# *1994*

# *ANNUAL REPORT*

# *RAPPORT ANNUEL*

# *1994*

| Submitted To: | Soumis au : |
|---|---|
| The MEND Board of Directors<br>Toronto, *April 19, 1995* | Conseil d'administration NEDEM<br>Toronto, *le 19 avril 1995* |

104-05361/

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**MEND/NEDEM**

*MINE ENVIRONMENT NEUTRAL DRAINAGE PROGRAM/*
*PROGRAMME DE LA NEUTRALISATION DES EAUX DE DRAINAGE*
*DANS L'ENVIRONNEMENT MINIER*

April 12, 1995

Mr. J. White
Chairman, MEND Board of Directors
Falconbridge Limited
Suite 1200
95 Wellington Street West
Toronto, Ontario
M5J 2V4

Dear Mr. White:

On behalf of the Management and Technical committees of MEND, I am pleased to submit to you the MEND Annual Report for 1994.

Copies have been sent to other Board members for their review before the Board meeting of April 19, 1995.

Yours truly,

I.J. Itzkovitch
Chairman
MEND Management committee

# MEND PARTICIPANTS NEDEM

Association minière du Québec
Atomic Energy Control Board
Barrick Gold Corporation
BHP Minerals Limited
British Columbia Ministry of Energy, Mines and Petroleum Resources
Brunswick Mining & Smelting Corporation Limited
Cambior Inc.
Canada Centre for Mineral and Energy Technology
Cape Breton Development Corporation
Centre de recherches minérales
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Denison Mines Limited
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Environment Canada
Falconbridge Limited
Fisheries and Oceans Canada
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Les Ressources Aur Inc.
Manitoba Department of Energy and Mines
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Ministère de l'Environnement et de la Faune du Québec
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Newfoundland and Labrador Department of Mines and Energy
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Ontario Ministry of Environment and Energy
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Placer Dome Inc.
Rio Algom Limited
Saskatchewan Environment and Resource Management
Teck Corporation
The Mining Association of British Columbia
The Mining Association of Canada
The Mining Association of Ontario
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## Associate Participants Associés

Australian Nuclear Science & Technology Organization
CETEM Brazil
Cogema Resources Inc.
Cigar Lake Mining Corporation
CRA Limited
CSIRO Minesite Rehabilitation Program
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Geological Survey of Canada
Metal Mining Agency of Japan
National Mine Land Reclamation Centre
Norwegian Pollution Control Authority
Laurentian University
Ontario Ministry of Natural Resources
Ontario Ministry of Labour
Swedish National Environmental Protection Board
United States Bureau of Mines
United States Environmental Protection Agency
University of British Columbia
University of Waterloo
University of Western Ontario
US Geological Survey

**MEND** (Mine Environment Neutral Drainage) is a co-operative research program sponsored, financed and administered by 3 partners; the Canadian mining industry, the Government of Canada and the Governments of the provinces of British Columbia, Manitoba, Ontario, Québec, New Brunswick, Saskatchewan, Nova Scotia and Newfoundland.

The objectives of MEND are to:

- provide a comprehensive, scientific, technical and economic basis for the mining industry and government agencies, to predict with confidence the long term management requirements for reactive tailings and waste rock; and
- establish techniques that will enable the operation and closure of acid-generating tailings and waste rock disposal areas in a **predictable, timely, affordable,** and **environmentally acceptable** manner.

Six committees direct and manage the technical components of the program: Prediction; Prevention & Control; Treatment; Monitoring; Technology Transfer; and International Liaison. These committees have specific mandates to develop techniques that reduce the environmental impact and financial liabilities caused by acidic drainage. A Management committee is responsible for managing the overall program and a Board of Directors reviews and approves budgets and program direction. The MEND Secretariat coordinates the activities of the committees and their respective programs. Participation in MEND is on a volunteer basis. Committee members contribute their time and expertise without financial compensation from MEND.

MEND is a 9-year program, scheduled for completion in December 1997. The research program was redefined in 1992 and is outlined in the **Revised Research Plan, 1992**. The results of MEND are being made widely available in reports, publications, seminars and workshops. Electronic copies and Internet access to reports are presently being arranged.

***NEDEM*** (Neutralisation des Eaux de Drainage dans l'Environnement Minier) est un programme de recherche qui est parrainé, financé et administré conjointement par 3 partenaires; l'industrie minière canadienne, le gouvernement fédéral et les gouvernements de la Colombie-Britannique, du Manitoba, de l'Ontario, du Québec, du Nouveau-Brunswick, de la Saskatchewan, de la Nouvelle-Écosse et de Terre Neuve.

Les objectifs du NEDEM sont les suivants:

- établir les fondements scientifiques, techniques et économiques permettant à l'industrie minière et aux organismes gouvernementaux de prédire avec confiance les besoins à long terme en matière de gestion des résidus réactifs et des stériles, et

- mettre au point des techniques permettant l'exploitation et l'abandon, de manière **prévisible, économique opportune et acceptable pour l'environnement**, des aires d'élimination de résidus miniers acides et des stériles.

Le programme est composé de 6 comités techniques: Prévision, Prévention et contrôle, Traitement, Surveillance, Transfert de la technologie et Liaison internationale. Ces comités ont des mandats spécifiques afin d'explorer les différentes voies permettant de réduire l'impact environnemental du drainage acide ainsi que l'engagement financier qu'il représente. Le comité de gestion est responsable de gérer le programme général et le conseil d'administration révisent et approuvent les budgets et la direction générale du programme. Le secrétariat NEDEM coordonne les comités techniques et leurs programmes respectifs. La participation au programme ce fait sur une base volontaire. Les membres des comités fournissent temps et expertise sans contribution financière de la part du NEDEM

NEDEM est un programme de 9 ans qui devrait être complété en décembre 1997. La direction du programme a été redéfinie en 1992 et est présenté dans le **Plan de recherche révisé 1992**. Les résultats du programme NEDEM sont publiés dans des rapports et des publications, et son également présentés à l'occasion de séminaires et d'ateliers. Il sera bientôt possible de se procurer des exemplaires des rapports sur diskettes et par le biais d'Internet.

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## TECHNICAL SUMMARY

MEND has completed 6 years of technology development for the control of acidic drainage from mine wastes. During 1994, the technical and management committees continued to direct the completion and reporting of research results that would result in a substantial reduction in the liabilities associated with acid mine drainage in Canada, and to complete this work within the budget and time approved by the Board of Directors.

In the three years remaining in the MEND program, the emphasis will shift from technology development to technology transfer, focusing on "having a good story to tell" at the end of the program in December, 1997. The results of MEND will be reported in documents, workshops, seminars, and at the Fourth International Conference on Acid Rock Drainage in Vancouver in June 1997, only two years in the future. As shown in Figure 1, MEND is close to being on target to remain within the budgetary ceiling of $18 million.

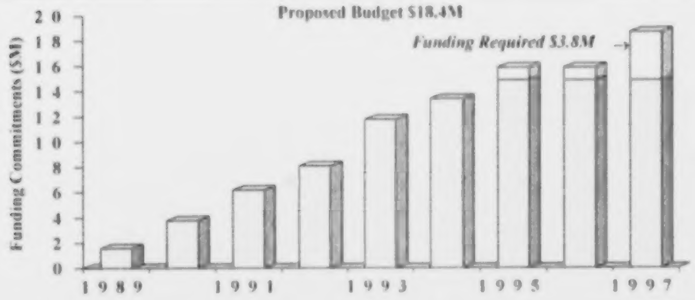

**Figure 1: Profile of MEND Expenditures 1989 - 1997**

In 1994, under the direction of a new Chairman, Mr. Bill Napier of Homestake Canada, the **Prediction committee** reconsidered the ambitious theoretical waste rock model development program that was proposed earlier. The Committee is now focused on the empirical approach, that is, use and analyze data from actual sites to develop simple protocols for prediction of acid generation in a pile of rock. This approach will result in simpler methods to analyze options for management of acid-generating waste rock. Studies completed at Mine Doyon in 1994 have provided an excellent data base on waste rock, and a detailed study for another type of waste rock is proposed for a Sudbury site.

Prediction is improving and documenting the chemical methods for determining the potential and rate of acid generation in mine wastes. Also, in cooperation with the Prevention and Control committee, Prediction has formulated a program to evaluate the potential for engineering a permafrost environment to prevent acidic drainage at mine sites in northern Canada.

1994 was a year of consolidation of results in the **Prevention and Control** program. Twenty-five projects were undertaken, and of these, 12 were completed. Underwater disposal and water covers are the "flagship" projects of MEND and very promising results continue to be demonstrated. Additional work was recommended by the first Peer Review in 1992. This and other work were completed with the following results:

☐ underwater disposal of **fresh**, reactive sulphide tailings and waste rock under water prevents acid generation in the natural environment; and

☐ water covers over partially **oxidized** tailings and waste rock are also attractive, but measures may need to be taken, such as the use of inexpensive surface diffusion layers, to prevent contamination of the water column.

MEND-sponsored water covers technology has moved to the field. Three uranium mine tailings sites in the Elliot Lake are being closed out using water covers. At the Solbec Cupra copper tailings site in south eastern Québec, the property owner has used the results of MEND research, and an economic analysis, to commence surface flooding for site remediation. The Louvicourt copper-zinc mine opened in northwest Québec **with underwater disposal of tailings**, and a monitoring program has been initiated at the Equity Silver tailings site in British Columbia. MEND is spending considerable resources in monitoring all of these tailings sites, in addition to continuing laboratory research on water covers over tailings and waste rock.

As directed by the MEND Board of Directors in 1994, the Prevention and Control committee has revisited the very large area of "dry" covers, keeping in mind that new cover types must be less costly than the multi-zone earth covers. Following the results of a contractor's report and economic analyses conducted by the committee, three types of materials were selected for further laboratory and field investigations:

☐ organic reductive covers;
☐ multi-zone covers built with tailings; and
☐ depyritized tailings.

Work is ongoing in all three areas.

In **Treatment,** the work on passive treatment systems was wrapped up with a contractor's report, in manual format, on passive treatment systems. Also completed was a summary of current practice on chemical treatment of acidic drainage. This work was presented in workshop format at Sudbury and Val d'Or. From these workshops and a review of the technical needs, the committee is recommending that, during the balance of the MEND program, the project focus will be the stability and disposal of lime treatment sludges. Work on metals removal prior to lime treatment did not show significant economic benefit to warrant going to pilot-scale demonstration.

The **Monitoring committee** completed projects on geophysical monitoring, remote sensing, analytical standards, and a Waste Rock Sampling Manual. Except for methods for oxygen flux measurement in the field, the only remaining identified project is the preparation of a summary document on monitoring techniques. This project, proposed for 1995, replaces expenditures approved in 1994 on additional geophysical technique development. A thorough review by the committee resulted in the decision that further expenditure in this area could not be justified.

The **New Ideas Task Force** concluded its second and final year of reviewing, selecting and managing small proof-of-concept contracts that have potential for significant breakthrough technology. Eighteen projects, costing $250,000 in total, have been administered, and 3 of these show promise for reduction in the cost of dealing with acidic drainage. These three technologies are being examined in a second proof-of-concept stage and the projects will be turned over to the technical committees for follow up.

**Technology Transfer** activities were significantly expanded during 1994, and this committee will assume an even larger role for MEND, up to and including the end of the program. The proactive Communications Plan recommended by the Board was put in place with newsletters, publications, a video on MEND, and a CIMM distinguished lecturer. MEND also has access to an Internet site for on-line retrieval of MEND documents. A World Wide Web site is currently under development. Workshops based on MEND project results were presented at three locations across Canada, and several more will be given in 1995.

MEND participated in the Third International Conference on the Abatement of Acidic Drainage in Pittsburgh in April, where 43 Canadian papers and posters were presented. Led by the British Columbia-based organizing committee, MEND looks forward to hosting visitors from Canada and around the world in June 1997 for the **Fourth International Conference on the Abatement of Acid Rock Drainage.** At this conference, the results of MEND will be presented in short courses, workshops and in technical papers.

A project on the economic evaluation of acid drainage technologies gave useful results including the demonstration of considerable site-specific influences on the cost of remedial technology. The following representative unit cost ranges (Net Present Value) were derived for the two basic AMD technologies (1994$/ha of tailings "footprint" or 1994$/tonne of waste rock):

| | **Per Hectare of Tailings** | **Per Tonne of Waste Rock** |
|---|---|---|
| **Collect and Treat** | 180,000 - 280,000<br>(210,000)* | 0.4 - 2.0<br>(0.70)* |
| **Minimal Maintenance (Dry Covers)** | 100,000 - 300,000<br>(200,000)* | 1.0 - 1.5<br>(1.30)* |

*average unit costs.

From a survey prepared by the Secretariat in 1994, a report summarizing mine waste liability was prepared for Mines Ministers and to the Parliamentary Standing Committee on Natural Resources. This report estimated the liabilities for acid generating mine wastes in Canada to be between $2 and $5 billion. Using the average costs (above) in the economic evaluation project, the liability is estimated to be between $3 and $3.6 billion.

## MEND ORGANIZATION

During the balance of the MEND program, steps will be taken to streamline committee operations. This is needed because much of the work has been completed, and two of the technical committees have a small amount of work remaining. The Prediction and Monitoring committees will hold their first joint meeting in June, and the Treatment committee will consider winding up in 1996. The New Ideas Task Force has been wrapped up, with the few on-going projects managed by the Secretariat. International liaison is now part of the Technology Transfer function.

International interest in the results of the Canadian MEND program remains strong and the network of contacts in foreign countries continues to expand. Several companies and organizations have expressed interest in participating in MEND as associate members, and these relationships will continue to increase in 1995.

CANMET, with the financial support of the Mining Association of Canada, will continue to provide the required level of Secretariat support for MEND until 1997.

## FINANCIAL REPORT

The financial commitment to MEND by its three partners, the Canadian Mining Industry, the Government of Canada, and the Provinces remained strong. Up to December 1994, $13 million had been spent and committed to 131 MEND-sponsored completed or active research projects as shown in Table 1.

**Table 1: Contributions to MEND 1988 to 1994 inclusive ($000's)**

| | Spent (%) Completed Projects | Spent & Committed (Active Projects) | Total (%) |
|---|---|---|---|
| Mining Industry | 3,945 (40.8) | 1,260 | 5,205 (39.9) |
| Canada | 3,345 (34.6) | 1,219 | 4,564 (35.1) |
| Provinces | 2,383 (24.6) | 879 | 3,262 (25.0) |
| **TOTALS** | **9,673** (100.0) | **3,358** | **13,031** (100.0) |

Of the total $13 million expenditure to date, the Prevention and Control component of the program has spent $7.4 million. This compares with a total budget allocation for Prevention and Control of $9.36 million.

In 1994, the Management committee directed the technical committees to examine priorities and estimate the budget needed to complete the MEND program. These estimates are shown in Table 2 below.

**Table 2: March 1995 estimates to complete the MEND program ($000's)**

| Technical Committee | March 1994 Budget (%) of total | New Estimates March, 1995 | % change + - |
|---|---|---|---|
| Prediction | 4,278 (23.8) | 3,844 | -10 |
| Prevention/Control | 9,361 (52.0) | 10,511 | +12 |
| Treatment | 1,734 (9.6) | 1,644 | -5 |
| Monitoring | 1,573 (8.7) | 1,085 | -32 |
| Tech. Trans. | 734 (4.1) | 1,064 | +45 |
| New Ideas | 320 (1.8) | 320 | --- |
| **TOTALS** | **18,000** (100.0) | **18,468** | +3 |

The currently estimated time profile for completion of key elements of the program is shown in Figure 2. Given previous years' availability of funding, and no major technological surprises, MEND should be able to meet the end of 1997 objective for completion. Some overlap into 1998 for technology transfer and monitoring of results of dry and wet covers may be required. The major cause for the program to not be completed on time may be the lack of funding for generic-type projects - eg., generation of design criteria.

Mineral Development Agreements (MDA's), the primary source of provincial funding and federal funding through CANMET, will not likely be renewed. In all provinces except Québec, these MDA's are in final, "wrap-up" years. MDA funds have been allocated to MEND in New Brunswick, Québec, Ontario, Manitoba and British Columbia, and at this time only about $0.8 million in federal funds remains uncommitted (Québec). For 1995, these agreements will continue to be significant sources of MEND funding for projects that are already ongoing, but with the exception of the Québec-Canada MDA, no new funds can be committed.

Tables 3 and 4 list the completed and active MEND projects as of the end of 1994. Table 5 lists projects which are being submitted to the Board for approval. These projects will cost $2,876k, for which $1,941k has been committed by the funding partners. The defined $18,000k Revised Research Plan budget and the total funds spent ($13,109k) on MEND projects are compared by the technical committee on Table 6. It also summarizes the budgets associated with the projects proposed for approval in 1995 ($2,876) which would bring the total program commitments to $15,985k.

Funding commitments to date are $13,031k for approved projects plus $1,941k for proposed projects for a total of $14,972k. **To complete the MEND program, $3,496k in new funding will need to be found between now and December 1997.**

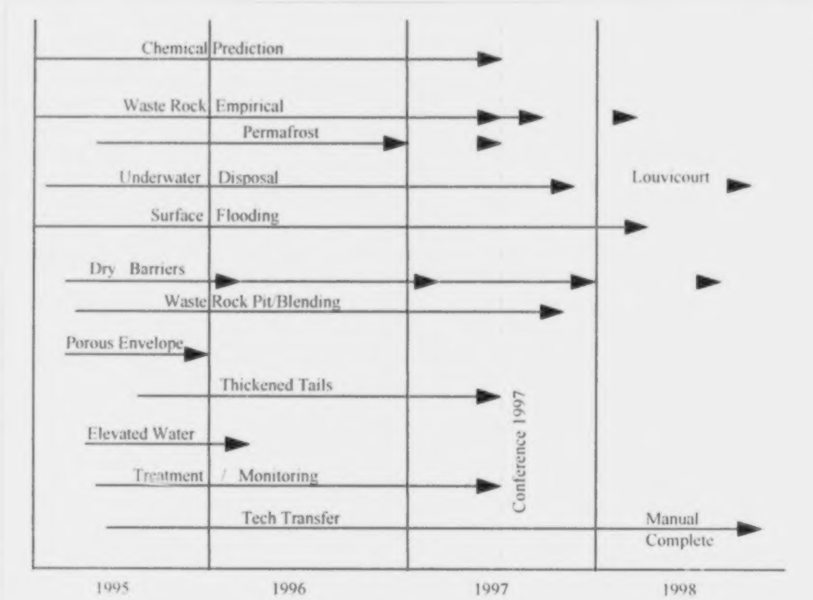

**Figure 2: Estimated Completion Dates for MEND Research Areas**

As illustrated in Table 6, a majority of the technical committees have committed a high proportion of their budgets. As in past years, the overall funding commitment to the MEND program will remain an issue for the Board of Directors to address. The reality of the current economic climate in Canada must be balanced with the need to reduce potential long term environmental liability to industry and governments. Also, the Board may wish to consider options for follow-up to, or continuation of the MEND program, such as the establishment of a small industry-government committee to monitor results of field programs.

Finally, on behalf of the Management committee, I want to express my thanks to all the volunteers and their supporting companies and agencies from the Canadian mining industry and government organizations across Canada. It is their contribution of time and expertise that is vital in maintaining the scientific credibility of the MEND program. In particular, the work by the chairmen of the technical committees; Mr. Bill Napier (Prediction); Mr. Len Surges and Mr. Wayne Fraser (Prevention and Control); Mr. Tom Hynes (Treatment); Mr. Ed Kustan (Monitoring); and Mr. Mike Sudbury (Technology Transfer) is recognised in making MEND a Canadian success story.

I.J. Itzkovitch, Chairman
MEND Management Committee
April 13, 1995

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## RÉSUMÉ TECHNIQUE

Le programme NEDEM est arrivé au terme de sa sixième année de mise en oeuvre. Pendant toutes ces années, l'objectif a été de mettre au point des techniques contre le drainage acide provenant des déchets miniers. En 1994, les comités techniques et le Comité de gestion ont continué de diriger des travaux de recherche visant à réduire de façon substantielle les coûts associés au drainage minier acide au Canada, et d'en publier les résultats, en s'appliquant à respecter le budget et les délais fixés par le Conseil d'administration.

Pendant les trois dernières années du programme NEDEM, la mise au point de technologies cédera la priorité au transfert de technologies et tout sera mis en oeuvre pour "avoir une bonne histoire à raconter" à la fin du programme, en décembre 1997. Les résultats du NEDEM seront présentés dans des publications, dans le cadre d'ateliers et de colloques, et à la quatrième conférence internationale sur le drainage rocheux acide qui se tiendra à Vancouver en juin 1997, c'est-à-dire dans deux ans seulement. Comme le montre la figure 1, le plafond budgétaire de 18 millions de dollars prévu pour le programme NEDEM devrait être respecté.

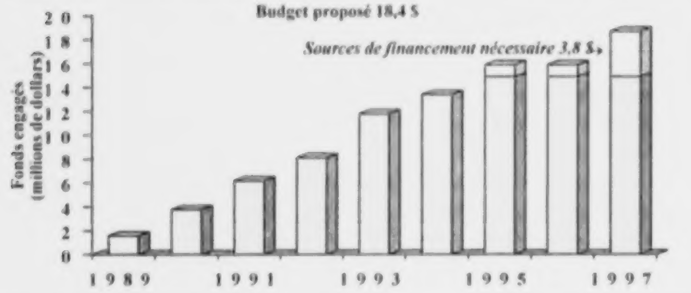


**Figure 1 : Profile des dépenses du NEDEM 1989-1997**

En 1994, sous la direction d'un nouveau président, M. Bill Napier de Homestake Canada, le **Comité de prévision** a réexaminé l'ambitieux programme d'élaboration d'un modèle théorique pour les stériles qui avait été proposé il y a quelque temps. Suite à cet examen, le comité a décidé de se concentrer sur la démarche empirique, c'est-à-dire d'utiliser et d'analyser des données recueillies sur le terrain en vue d'élaborer des modèles simples de prévision de la production d'acide dans un amas de roches. Le comité espère ainsi disposer de méthodes plus simples pour analyser les différentes possibilités de gestion des haldes de stériles à l'origine du drainage acide. Les études réalisées à la mine Doyon en 1994 ont permis la mise en place d'une excellente base de données sur les stériles et il a été proposé d'effectuer une étude détaillée d'un autre type de stériles dans une mine de la région de Sudbury.

Le Comité de prévision travaille à l'amélioration et à la documentation des méthodes chimiques utilisées pour déterminer le potentiel et la vitesse d'acidification dans les stériles. Par ailleurs, en collaboration avec le Comité de prévention et contrôle, le Comité de prévision a élaboré un programme permettant d'évaluer la possibilité d'intervention technique dans le pergélisol pour empêcher le drainage acide dans les mines canadiennes situées dans les régions septentrionales.

1994 a été une année de consolidation des résultats pour le **Comité de prévention et contrôle** . Douze des vingt-cinq projets entrepris sont terminés. L'élimination subaquatique et l'utilisation de couvertures aqueuses constituent les projets "vedettes" du NEDEM et la recherche dans ce domaine continue de donner des résultats très prometteurs. Comme il a été recommandé par une révision des pairs en 1992, des travaux additionnels ont été réalisés, dont voici les résultats :

☐ l'élimination subaquatique des résidus et des stériles sulfurés réactifs **non oxydés** prévient l'acidification du milieu naturel;

☐ l'utilisation de couvertures aqueuses sur des résidus et des stériles partiellement **oxydés** est également attrayante, mais il se peut que l'on doive prendre des mesures pour empêcher la contamination de la colonne d'eau, comme, par exemple, employer des couches de diffusion superficielles.

Des projets d'utilisation de couvertures aqueuses, financés par le NEDEM, sont maintenant en cours sur le terrain. La technique est employée dans trois parcs à résidus de mines d'uranium à Elliot Lake. Le propriétaire de la mine de cuivre Solbec Cupra, dans le sud-est du Québec, s'est basé sur les résultats de recherches effectuées dans le cadre du NEDEM, ainsi que sur des résultats d'analyses économiques, pour installer d'une couverture aqueuse en vue de la remise en état du site. Les résidus de la mine de cuivre-zinc Louvicourt, qui vient d'ouvrir dans le nord-ouest du Québec, seront éliminés par la technique subaquatique, et un programme de surveillance a été mis sur pied dans le parc à résidus Equity Silver, en Colombie-Britannique. Des ressources considérables sont engagées dans le cadre du NEDEM pour la surveillance de tous ces parcs à résidus, en plus des recherches effectuées en laboratoire sur les couvertures aqueuses pour les résidus et les stériles.

En 1994, à la demande du Conseil d'administration, le Comité de prévention et contrôle a revu la très vaste question des barrières "sèches", en tenant compte du fait que les nouveaux types de couverture doivent être moins coûteux que les couvertures de terre multi-zones. En se basant sur les résultats publiés dans un rapport d'entrepreneur et sur des analyses économiques qu'il avait lui-même exécutées, le comité a choisi trois types de matériaux pour la poursuite des recherches en laboratoire et sur le terrain :

☐ couvertures organiques réductrices;
☐ couvertures multi-zones construites à partir de résidus; et
☐ résidus dépyritisés.

Des travaux sont en cours dans les trois domaines.

En ce qui concerne le **traitement**, les résultats des travaux sur le traitement passif ont été inclus dans un rapport d'entrepreneur, sous forme de manuel, consacré aux systèmes de traitement passif. Le comité a également rédigé un résumé des méthodes actuelles utilisées pour le traitement chimique des eaux de drainage acides; le travail a été présenté dans le cadre de deux ateliers à Sudbury et Val d'Or. En se basant sur ces ateliers et sur un examen des besoins techniques, le comité recommande que, à partir de maintenant et jusqu'à la fin du NEDEM, l'accent soit mis sur la stabilité et l'élimination des boues traitées à la chaux. Les recherches effectuées dans le cadre du NEDEM sur l'élimination des métaux avant la neutralisation à la chaux ont donné des résultats décevants en ce qui concerne la rentabilité de cette technique et il a été décidé de ne pas passer à l'étape de la démonstration à l'échelle pilote.

**Le Comité de surveillance** a terminé des travaux consacrés à la surveillance géophysique, à la télédétection et aux normes analytiques, ainsi que la rédaction d'un manuel sur l'échantillonnage des stériles. En dehors des méthodes de mesure du flux d'oxygène sur le terrain, le seul projet identifié est la préparation d'un résumé des techniques de surveillance. Ce projet, proposé pour 1995, remplace un autre projet sur la mise au point d'une technique géophysique, qui avait été approuvé en 1994. Après un examen exhaustif, le comité avait conclu que des dépenses additionnelles dans ce domaine n'étaient pas justifiées.

**Le Groupe de travail sur les nouvelles idées** a terminé sa seconde et dernière année d'analyse, de sélection et de gestion de petits contrats de preuve de concepts offrant la possibilité d'effectuer une percée technologique importante. Dix-huit projets, au coût total de 250 000 $, ont été administrés et trois d'entre eux ont donné des résultats prometteurs en ce qui concerne la réduction des coûts de la lutte contre le drainage acide. Une deuxième étape de preuve de concepts est en cours pour ces trois technologies et les projets seront acheminés aux comités techniques pour le suivi.

Les activités liées au **transfert de la technologie** ont connu une expansion considérable en 1994 et le Comité de transfert de la technologie jouera un rôle encore plus important dans le programme NEDEM, jusqu'à la fin du programme. Le plan de communication proactif recommandé par le Conseil d'administration a été mis à exécution : des bulletins d'information et des rapports ont été publiés, un vidéo sur le NEDEM a été produit et un conférencier éminent a été nommé auprès de l'ICMM. Des ateliers, au cours desquels des résultats de contrats exécutés dans le cadre du NEDEM ont été présentés, se sont tenus dans trois villes au Canada et plusieurs autres sont prévus en 1995.

Le NEDEM a participé à la troisième Conférence internationale sur la réduction des eaux de drainage acides, qui s'est tenue à Pittsburgh, en avril; 43 exposés et séances d'affichage canadiens ont été présentés. La **quatrième Conférence internationale sur le drainage rocheux acide**, à laquelle sont attendus des participants venant de tous les coins du monde, aura lieu en juin 1997. Son organisation a été confiée à un comité organisateur basé en Colombie-Britannique. Les résultats du programme NEDEM seront présentés à cette conférence par le biais de cours abrégés, d'ateliers et de communications techniques.

Un projet portant sur l'évaluation économique de techniques de lutte contre le drainage acide a donné des résultats utiles. On a en particulier démontré l'influence considérable de facteurs liés à l'emplacement sur le coût des techniques de remise en état. Les coûts unitaires suivants sont représentatifs des deux grandes techniques utilisées pour lutter contre le DMA ($ 1994/ha de résidus ou $ 1994/tonne de stériles) :

| | **Par hectare de résidus** | **Par tonne de stériles** |
|---|---|---|
| **Pompage et traitement** | 180 000 - 280 000<br>(210 000)* | 0,4 - 2,0<br>(0,70)* |
| **Entretien minimal (barrières sèches)** | 100 000 - 300 000<br>(200 000)* | 1,0 - 1,5<br>(1,30)* |

*coûts unitaires moyens.

Selon un rapport préparé par le Secrétariat en 1994, le fardeau financier des sites miniers acides au Canada est entre 2 et 5 milliards de dollars. Ce rapport a été soumis aux ministres des Mines et au Comité permanent des Ressources naturelles de la chambre des communes.

Si l'on se base sur ces coûts moyens (ci-haut), ainsi que sur les résultats d'une enquête menée en 1994 par le Secrétariat du NEDEM, le fardeau financier du drainage minier acide au Canada s'établit actuellement entre 3,0 et 3,6 milliards de dollars.

## ORGANISATION DU NEDEM

Pendant les années restantes du NEDEM, des mesures seront prises pour rationaliser le fonctionnement des comités. Cette rationalisation est devenue nécessaire parce qu'une grande partie du travail a été réalisée et que deux des comités techniques ont maintenant une tâche réduite. Le Comité de prévision et le Comité de surveillance tiendront leur première réunion commune en juin et le Comité de traitement devrait terminer ses travaux en 1996. Le Groupe de travail sur les nouvelles idées a été dissous et les quelques projets en cours sont maintenant gérés par le Secrétariat. Les relations internationales relèvent maintenant du Comité de transfert de la technologie.

Les résultats du programme NEDEM canadien continuent de susciter un grand intérêt à l'échelle internationale et les liens avec les spécialistes étrangers se multiplient. Plusieurs entreprises et organismes ont exprimé leur désir de participer au programme en tant que membres associés et l'on s'attend à ce que le réseau s'étende encore en 1995.

CANMET, aidé financièrement par l'Association minière du Canada, continuera d'apporter le soutien nécessaire au NEDEM, au chapitre du Secrétariat, jusqu'en 1997.

## RAPPORT FINANCIER

La contribution financière au NEDEM par ses trois partenaires, l'industrie minière canadienne, le Gouvernement du Canada et les provinces, est demeurée élevée. En décembre 1994, 13 millions de dollars avaient été dépensés à 131 projets de recherche complétés ou en cours parrainés par le NEDEM (tableau 1).

**Tableau 1 : Contributions au NEDEM de 1988 à 1994 inclusivement (en milliers de dollars)**

| | Dépensées (%) Projets Complétés | Engagées et Dépensées (Projets en cours) | Total (%) |
|---|---|---|---|
| Industrie minière | 3 945 (40,8) | 1 260 | 5 205 (39,9) |
| Canada | 3 345 (34,6) | 1 219 | 4 564 (35,1) |
| Provinces | 2 383 (24,6) | 879 | 3 262 (25,0) |
| **TOTAUX** | **9 673** (100,0) | **3 358** | **13 031** (100,0) |

Sur les 13 millions de dollars déjà dépensés, 7,4 millions ont été consacrés à la prévention et au contrôle . Le budget total alloué à ce chapitre était de 9,36 millions de dollars.

En 1994, le Comité de gestion a demandé aux comités techniques d'examiner les priorités et d'évaluer les montants nécessaires pour terminer le programme NEDEM. Les prévisions sont indiquées dans le tableau 2 ci-dessous.

**Tableau 2 : Prévisions budgétaires en mars 1995, pour terminer le programme NEDEM**
**(en milliers de dollars)**

| Comité technique | Budget en mars 1994 (%) | Prévisions mars 1995 | % de changement + - |
|---|---|---|---|
| Prévision | 4 278 (23,8) | 3 844 | -10 |
| Prévention et Contrôle | 9 361 (52,0) | 10 511 | +12 |
| Traitement | 1 734 (9,6) | 1 644 | -5 |
| Surveillance | 1 573 (8,7) | 1 085 | -32 |
| Transfert de la technologie | 734 (4,1) | 1 064 | +45 |
| Nouvelles Idées | 320 (1,8) | 320 | --- |
| **TOTAUX** | **18 000** (100,0) | **18 468** | +3 |

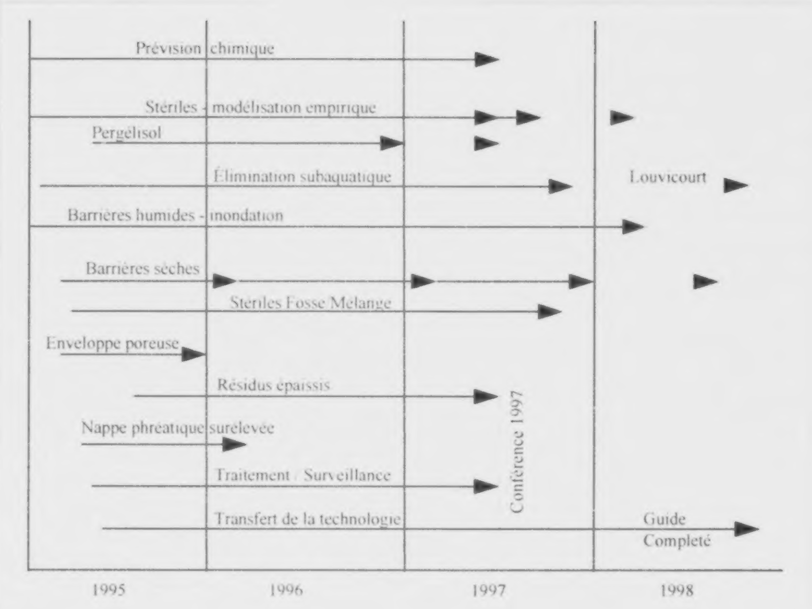
Les délais actuels prévus pour l'exécution des éléments clés du programme sont indiqués sur la figure 2. D'après les données des années antérieures concernant le financement, s'il ne surgit pas de surprises technologiques, l'objectif devrait être atteint et le programme NEDEM devrait être terminé à la fin de 1997; on prévoit toutefois que certains projets (transfert de la technologie et surveillance des résultats des barrières sèches et humides) pourraient se prolonger jusqu'en 1998. La principale raison pour laquelle le programme ne serait pas terminé à temps pourrait être un manque de financement de projets généraux tel, par exemple, le projet concernant l'établissement de critères de conception.

Les Ententes sur l'exploitation minérale (EEM), principale source de financement provincial et fédéral, par l'intermédiaire de CANMET, sont sur le point d'expirer sauf au Québec. Des fonds prévus dans les EEM ont été affectés à des projets du NEDEM au Nouveau-Brunswick, au Québec, en Ontario, au Manitoba et en Colombie-Britannique, et, à ce jour, le montant des fonds fédéraux qui n'ont pas encore été engagés (Québec) s'élève seulement à environ 0,8 million de dollars. En 1995, ces ententes constitueront d'importantes sources de financement pour les projets de NEDEM qui sont en cours, mais aucun nouveau montant ne peut être engagé.

Les tableaux 3 et 4 indiquent les projets du NEDEM complétés et en cours d'exécution à la fin de 1994. Le tableau 5 indique les projets présentés au Conseil d'administration pour approbation. Ces projets coûteront 2 876 000 $, dont 1 941 000 ont été engagés par les partenaires financiers. Le tableau 6 compare le budget défini par le Plan de recherche révisé (18 000 000 $), par comité technique, avec les fonds totaux dépensés et engagés dans les projets du NEDEM à ce jour (13 109 000 $). Il résume également les budgets associés aux projets proposés pour 1995 (2 876 000 $), ce qui porterait les engagements totaux à 15 985 000 $.

Les engagements jusqu'à ce jour sont de 14 972 000 $. **D'ici décembre 1997, il faudra trouver 3 500 000 $ auprès de nouvelles sources de financement pour terminer le programme.**

**Figure 2 : Dates prévues pour l'achèvement des domaines de recherches du NEDEM**


Prévision chimique
Stériles - modélisation empirique
Pergélisol
Élimination subaquatique
Louvicourt
Barrières humides - inondation
Barrières sèches
Stériles Fosse Mélange
Enveloppe poreuse
Résidus épaissis
Nappe phréatique surélevée
Traitement / Surveillance
Conférence 1997
Transfert de la technologie
Guide
Completé
1995
1996
1997
1998

Tel qu'illustré au tableau 6, la majorité des comités techniques ont engagé une proportion élevée de leur budget. Comme durant les années passées, le Conseil d'administration devra se pencher sur le problème de l'engagement financier global au programme NEDEM. La réalité du climat économique actuel au Canada ne doit pas faire oublier le besoin de réduire la responsabilité environnementale à long terme qui pourrait incomber à l'industrie et aux gouvernements. Enfin, le Conseil voudra peut-être envisager un suivi au programme NEDEM comme, par exemple, la mise en place d'un petit comité mixte industrie-gouvernement chargé de surveiller les résultats des travaux exécutés sur le terrain.

Au nom du Comité de gestion, je désire remercier tous les volontaires ainsi que les entreprises et organismes qui, par leur soutien, n'ont cessé de contribuer au succès du programme NEDEM.
Leur apport est vital à la crédibilité scientifique du programme. En particulier, je souligne le travail des présidents de comités techniques, M. Bill Napier (Prévision), M. Len Surges et M. Wayne Fraser (Prévention et contrôle), M. Tom Hynes (Traitement), M. Ed Kustan (Surveillance) et M. Mike Sudbury (Transfert de la technologie) qui on fait de NEDEM un succès canadien.

I.J. Itzkovitch, Président
Comité de gestion du NEDEM
13 avril 1995

## Table 3: Completed Projects

| Project | Title | Budget ($000's) | Expenditures ($000's) | Variance ($000's) | Sponsors ($000's) |
|---|---|---|---|---|---|
| 1.11.1 | AMD from Waste Rock - Literature Review | 50 | 50 | 0 | Env. Can. (25), Teck (25) |
| 1.12.1a | Compile AMD Prediction Data - Tailings & Waste Rock | 45 | 44.6 | 0.4 | B.C. (32.3), CANMET (12.3) |
| 1.14.1 | Field Evaluation Rock Hydrogeochemistry - Mine Doyon | 362 | 362 | 0 | Québec (94), Lac (134), Cambior (134) |
| 1.14.2 | Mine Doyon Phase II - Monitoring and Modelling | 450 | 450 | 0 | Cambior (75), CANMET (150), Québec (150), Lac (75) |
| 1.15.1a | AMD from Open Pits - Equity Silver | 55 | 53 | 2 | B.C. (10), CANMET (10), Placer Dome (33) |
| 1.16.1a | Evaluation of Prediction Techniques - Tailings & Waste Rock | 70 | 63 | 7 | CANMET (63) |
| 1.16.1b | Manual of Chemical Evaluation Procedures | 23 | 23 | 0 | CANMET (23) |
| 1.16.1c | Development of Static Evaluation Procedures | 40 | 21 | 19 | CANMET (21) |
| 1.16.2a | Interlaboratory Program for Standard Material NBM-1 | 20 | 20 | 0 | CANMET (10), Env. Can. (10) |
| 1.17.1 | Hydrogeochemical Investigation - Waite Amulet | 235 | 285 | (50) | CANMET (117), Noranda (168) |
| 1.19.1 | Kinetic Tests for Cinola Gold Project | 100 | 94.3 | 5.7 | Env.Can. (47), B.C. (25), City Res. (2.4), CANMET (20) |
| 1.21.1a | Evaluate RATAP.BMT Capabilities | 30 | 30 | 0 | CANMET (30) |
| 1.21.1b | Workshop of Modelling Techniques - Tailings | 70 | 73 | (3) | CANMET (63), Falconbridge (10) |
| 1.21.1c | Prepare RATAP Users Manual | 30 | 19 | 11 | Env. Can. (19) |
| 1.22.1 | ANSTO Model at Heath Steele | 145 | 145 | 0 | CANMET (87.3), N.B. (22.7), Noranda (35) |
| 1.24.1 | Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps | 285 | 21 | 264 | DIAND (21) |
| 1.25.1 | Development of a Soil Flux Model to Design Tailings Covers | 49.5 | 55.8 | (6.3) | CANMET (56) |
| 1.26.1 | Development of Modelling Methodology for Prediction of Seepage from Acid-generating Waste Rock | 90 | 90 | 0 | Env. Can. (30), B.C. (60) |
| 1.31.1 | Fundamental Reaction Kinetics - SIMS | 95 | 98.6 | (3.6) | Echo Bay (5), DIAND (18), Ontario (53.5), INCO (22.1) |
| 1.32.1 | Prediction and Prevention of ARD - A Geological & Mineralogical Approach | 73 | 71.4 | 0 | Env. Can. (52), Teck (3), HBM&S (3), BHP (3), Placer Dome (3), Cominco (3), Homestake (3) |
| 1.41.1 | International Workshop on Waste Rock Modelling | 10 | 7.8 | 2.2 | CANMET (0.5), Noranda (0.8), Falconbridge (0.8), Québec (0.8), B.C. (0.8), HBM&S (0.8), INCO (0.8), Ontario (0.8), Teck (0.8) |
| 1.41.2 | ARD Waste Rock Monitoring Database | 22 | 22 | 0 | CANMET (22) |
| 1.51.1 | Quantitative Analysis of Chemical and Biological Kinetics | 12 | 11.8 | 0.2 | Env. Can. (11.8) |
| 1.51.2 | Non-linear Modelling of Chemical Kinetics for AMD | 30 | 34.6 | (4.6) | Env. Can. 34.6 |
| 2.11.1a | Evaluation of Existing Underwater Disposal Sites | 210 | 220 | (10) | B.C. (50), CANMET (70), HBM&S (65), Env. Can. (35) |
| 2.11.1b | Evaluation of Existing Underwater Disposal Sites | 250 | 136 | 114 | B.C. (5), CANMET (5), HBM&S (50), Env. Can. (26), Placer Dome (50) |
| 2.11.1c | Evaluation of Existing Underwater Disposal Sites | 50 | 68 | (18) | Placer Dome (68) |
| 2.11.1d | Peer Review on the Subaqueous Disposal of Tailings | 45 | 34 | 11 | CANMET (32.4), Placer Dome (2) |
| 2.11.2a | Literature Review - Metal Toxicology | 16.3 | 16.3 | 0 | Placer Dome (16) |
| 2.11.3a,b,c | Evaluation of Underwater Disposal Site - Anderson Lake | 400 | 410 | (10) | HBM&S (214), CANMET (100), Manitoba (90), Env. Can. (6) |
| 2.13.1 | Flooding of Exisiting Tailings Sites - Quirke Lake | 835 | 835 | 0 | Rio Algom (502), CANMET (333) |
| 2.13.2a,b,c | Flooding of Exisiting Tailings Sites - Solbec Cupra | 260 | 291 | (31) | Cambior (99), CANMET (103), Québec (88) |
| 2.13.3 | Flooding of Exisiting Tailings Sites - Falconbridge | 170 | 170 | 0 | Falconbridge (155), Ontario (15) |
| 2.14.1 | Establish Vegetative Wetlands Over Tailings | 100 | 30 | 70 | Falconbridge (25), CANMET (5) |

***Table 3: Completed Projects Continued***

| Project | Title | Budget ($000's) | Expenditures ($000's) | Variance ($000's) | Sponsors ($000's) |
|---|---|---|---|---|---|
| 2.20.1 | Evaluation of Dry Covers for the Prevention of Acid Mine Drainage from Tailings | 50 | 55 | (5) | CANMET (25), Ontario (25), Lac (5) |
| 2.21.1 | Engineered Dry Covers for Tailings | 230 | 216 | 14 | Env. Can. (61), CANMET (35), DSS (120) |
| 2.21.2 | Engineered Dry Covers for Tailings - Noranda | 469 | 533 | (64) | CANMET (161), Noranda (220), Québec (152) |
| 2.22.1 | Assessment of Hardpan | 150 | 100.5 | 49.5 | Manitoba (101) |
| 2.23.1 | Documentation of Disposal Methods - Tailings & Waste Rock | 75 | 75 | 0 | B.C. (38), CANMET (37) |
| 2.23.2a,b | Thickened Tailings Disposal (TTD) Method | 148.7 | 155.7 | (7) | Falconbridge (155.7) |
| 2.23.2d | Geochemical Evaluation of TTD System at Kidd Creek | 250 | 260 | (10) | Falconbridge (140), Ontario (60), CANMET ( 60) |
| 2.23.3 | Porous Envelope Disposal Method - Falconbridge | 190 | 207 | (17) | Falconbridge (116), Ontario (76), CANMET (15) |
| 2.24.1 | Vegetation Manual | 35 | 33.5 | 1.5 | CANMET (34) |
| 2.25.1 | Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost | 130 | 86 | 44 | Falconbridge (53.5), Ontario (32.5) |
| 2.25.2 | Design of an Organic Barrier Using Wood Waste - East Sullivan | 431 | 210 | 221 | Québec (210) |
| 2.31.1a | Dry Covers on Waste Rock - Heath Steele | 400 | 312 | 88 | BM&S (172), New Brunswick (140) |
| 2.32.1 | Blending and Segregation of Waste Rock - Kutcho Creek | 140 | 140 | 0 | Sumac (110), B.C. (15), CANMET(15) |
| 2.32.2a | Co-disposal of Tailings and Waste Rock - Mines Selbaie | 96 | 96 | 0 | Québec (76), CANMET (20) |
| 2.32.2b | Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review | 10 | 10 | 0 | Québec (10) |
| 2.34.1 | Cementitious Covers | 130 | 130 | 0 | Westmin (100), CANMET (30) |
| 2.41.1a | Electrochemical Oxidation/Passivation of Sulphides | 60 | 60 | 0 | HBM&S (10), Lac (10), Noranda (5), CANMET (35) |
| 2.42.1 | Development of Synthetic Polymers | 45 | 45 | 0 | INCO (22.5), Ontario (22.5) |
| 2.44.1 | Microbial Plugging | 100 | 100 | 0 | CANMET (60), INCO (10), Noranda (20), Teck (10) |
| 2.45.1a | Separation of Sulphides from Mill Tailings - Phase I | 75 | 75 | 0 | Ontario (20), CANMET (20), Lac (15), Placer (10), Selbaie (10) |
| 3.11.1a | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology | 230 | 281 | (51) | INCO (166), CANMET (40), Denison (25) Env. Can. (50) |
| 3.11.1b | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology | 250 | 273 | (23) | INCO (83), CANMET (90), Denison (30) Env. Can. (70) |
| 3.11.1c | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology | 128 | 125 | 3 | Env. Can. (27), CANMET (27), Québec (30) INCO (25), Denison (16) |
| 3.11.1d | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology | 80 | 80 | 0 | Env. Can. (20), CANMET (20), Québec (20), INCO (20) |
| 3.12.1 | Assessment of Existing Natural Wetlands | 40 | 40 | 0 | Env. Can. (40) |
| 3.12.2 | Evaluation of Panel Wetlands | 45 | 45 | 0 | CANMET (22.5), Ontario (22.5) |
| 3.21.1a | Metals Recovery from Acid Mine Drainage | 25 | 25 | 0 | CANMET (10), Env. Can. (15) |
| 3.21.2a | Removal of Metals - Chemical | 100 | 90 | 10 | Noranda (90) |
| 3.22.1 | Survey of Acid Mine Drainage Characteristics | 15 | 15 | 0 | Ontario (15) |
| 3.32.1 | Chemical Treatment - Review and Sludge Stabilization | 60 | 60 | 0 | Ontario (30), CANMET (30) |

***Table 3: Completed Projects Continued***

| Project | Title | Budget ($000's) | Expenditures ($000's) | Variance ($000's) | Sponsors ($000's) |
|---|---|---|---|---|---|
| 4.1.1 | Field Methods Manual - Tailings | 20 | 29 | (9) | CANMET (29) |
| 4.2.1 | Decommissioning Criteria | 15 | 15 | 0 | Ontario (5), HBM&S (5), Homestake (5) |
| 4.3.1 | Standard Reference Materials - Tailings | 50 | 50 | 0 | CANMET (50) |
| 4.3.2 | Standard Material - Net Neutralization Potential | 28 | 27.5 | 0.5 | Env. Can. (25), CANMET (2.5) |
| 4.5.1 | Field Methods Manual - Waste Rock | 55 | 55 | 0 | INCO (25), Homestake (10), Env. Can. (10), AECB (10) |
| 4.5.2 | Field Sampling QA/QC | 9.5 | 9.5 | 0 | Noranda (9.5) |
| 4.5.3 | ARD Technical Guide - Monitoring Section | 53.7 | 53.7 | 0 | CANMET (50), Env. Can. (3.7) |
| 4.6.1 | Assessment of Geophysical Techniques | 118 | 130.6 | (12.6) | Ontario (38), CANMET (38), INCO (54.6) |
| 4.6.2 | Continuous Monitoring of AMD - Literature Review | 50 | 50 | 0 | Québec (50) |
| 4.6.3 | Remote Monitoring Techniques - Review | 60 | 60 | 0 | Ontario (30), CANMET (30) |
| 4.6.4 | Piezocone Field Test | 26.7 | 26.7 | 0 | INCO (9), Ontario (17.7) |
| 4.7.1 | Optimum Sampling Frequence | 27 | 27 | 0 | B.C. (13.5), CANMET (13.5) |
| 4.7.2 | Biological Monitoring of Acid Mine Drainage | 21 | 21 | 0 | B.C. (10.5), CANMET (10.5) |
| 4.7.3 | Aquatic Invertebrate Monitoring | 136 | 136 | 0 | B.C. (75), CANMET (42), Env. Can. (4), Noranda (15) |
| 4.7.4 | Acid Mine Drainage Sediment Monitoring | 6.5 | 6.5 | 0 | B.C. (4), CANMET (2.5) |
| 4.7.5 | Ion Speciation | 35 | 35 | 0 | B.C. (6), CANMET (6), Noranda (23) |
| 4.7.6 | Paleolimnology Techniques | 16.5 | 16.5 | 0 | Noranda (16.5) |
| 4.8.1 | Monitoring of the Flooded Solbec Pit | 139 | 136.5 | 3.5 | CANMET (30), Québec (106.5) |
| 4.8.2 | Sediment Sampling Probe - Field Application | 51.1 | 51.1 | 0 | CANMET (17.04), Falconbridge (12), INCO (5), Ontario (17.04) |
| 5.1.1a-c | Provincial Workshops | 56 | 29.3 | 26.7 | Ontario (9.3), Québec (20) |
| 5.3.1 | Laurentian Database | 35 | 35 | 0 | Ontario (35) |
| 5.3.2 | Expand Databases at Laurentian & UBC | 40 | 12 | 28 | Ontario (12) |
| 5.4.1 | ARD Technical Guide - version française | 24 | 24 | 0 | Québec (24) |
| 5.5.1 | Preliminary MEND Research Plan | 25 | 25 | 0 | CANMET (25) |
| 5.6.1 | Second International Conference on the Abatement of Acidic Drainage | 127 | 127 | 0 | CANMET (30), Teck (8), Env. Can. (15), Cominco (5), Rio Algom (4), Falconbridge (4), Placer Dome (4), INCO (11), Noranda (20), Cambior (4), MITEC (7), HBM&S (3), Ontario (7), B.C. (3), MAC (2), Québec (10) |
| 5.6.2 | Third International Conference on the Abatement of Acidic Drainage | 15 | 12 | 3 | AMQ (4), Ontario (5), CANMET (3) |
| 5.8.1 | Economic Evaluation of MEND-Developed Technology | 40 | 40 | 0 | Ontario (40) |
| 6.1 | New Ideas Round One | 203 | 140.9 | 62.1 | CANMET (44.4), DIAND (9.2), Teck (20), INCO (10), Lac (10), Noranda (10), HBM&S (15), Ontario (20), Québec (20), AMQ (10) |
|  | Totals | 10,398.5 | 9,671.7 | 726.8 | 95/04/02 |

## Table 4: Active Projects

| Project | Title | Approved Budget ($000's) | Expenditures ($000's) | Variance ($000's) | Sponsors ($000's) |
|---|---|---|---|---|---|
| 1.12.1b | DBARD - Continuation | 40 | 25 | 15 | Env. Can. (20), CANMET (20) |
| 1.14.3 | Mine Doyon Comprehensive Review | 65 | ---- | 65 | CANMET (65) |
| 1.15.2 | AMD from Open Pits - Expansion & Verification of Model | 88 | 80 | 8 | CANMET (53), Noranda (20.06) BHP(14.6) |
| 1.19.2 | Evaluation of Scaling - Bench, Pilot and Field Scale | 21 | 10 | 11 | Env. Can. (15) |
| 1.21.2 | Pyrrhotite Oxidation - Laboratory and Modelling Studies | 100 | 15 | 85 | CANMET (30), Ontario (30), Noranda (20), INCO (20) |
| 1.31.2 | Residual Weathering Production Waste Rock Dumps | 40 | 20 | 20 | B.C. (20), Placer Dome (10) |
| 1.32.2 | Pyrite Oxidation - Lithological & Mineralogical Factors | 40 | 19.1 | 20.9 | B.C. (20), Homestake (5.3) |
| 1.42.1 | Critical Review of Geochemical Modelling | 64 | 54 | 6 | Ontario (30), CANMET (30), Teck (4) |
| | | | | | |
| 2.11.4a | Evaluation of Underwater Disposal Sites - Buttle Lake | 250 | 200 | 50 | CANMET (150), Placer Dome (94), Env. Can. (6) |
| 2.11.5a | Shallow Water Covers - Equity Silver | 80 | 44 | 36 | Placer Dome (44) |
| 2.11.9 | Underwater Disposal Sites - Design Criteria | 50 | 0 | 50 | |
| 2.12.1a,b | Man-made Lakes Disposal - Louvicourt | 350 | 27 | 323 | CANMET (27) |
| 2.13.2d | Monitoring of the Flooded Solbec Cupra Tailings Site | 150 | 30 | 120 | Cambior (24), Qudbec (70) |
| 2.15.1 | Water Covers - Laboratory/ Field | 487 | 298 | 189 | Noranda (253), INCO (85), Lac (15), Ontario (30) |
| 2.20.1 | Evaluation of Alternate Dry Covers | 50 | 40 | 10 | CANMET (25), Ontario (25), Lac (5), DIAND (32) |
| 2.21.3 | Peer review of Waite Amulet and Heath Steele Soil Covers | 50 | 0 | 50 | Cominco (47) |
| 2.21.4 | Protocols for Engineered Dry Covers | 30 | 0 | 30 | |
| 2.22.2a | Evaluation of Dry Covers Built from Mine Tailings | 235 | 270 | (35) | Québec (133), Itec (20), Lac (10), CANMET (107) |
| 2.23.2c | TTD - Tracer Study | 78 | 35 | 43 | Falconbridge (39), Ontario (20), CANMET (20) |
| 2.31.1b | Dry Covers on Waste Rock - Heath Steele | 368 | 350 | 18 | Noranda (121.3), N.B. (91.9), CANMET (154.5) |
| 2.35.2 | Lysimeter Covers for Waste Rock | 275 | 250 | 25 | Noranda (152), Québec (84), CANMET (43) |
| 2.36.1 | In-pit Disposal - Case Studies | 50 | 20 | 30 | Ontario (20), CANMET (20), HBM&S (10) |
| 2.36.2 | In-pit Diposal of Oxidized Waste Rock | 166 | 0 | 166 | Noranda (78), CANMET (50) |
| | | | | | |
| 3.14.1 | Review of Passive Systems for Treatment AMD | 60 | 54 | 6 | CANMET (30), Ontario (30) |
| 3.21.1b | Removal of Metals - Ion Exchange | 64 | 64 | 0 | Teck (10), Falconbridge (4), Ontario (30), Homestake (20) |
| 3.31 | Use of Lime Sludges for Capping | 30 | 12 | 18 | INCO (6.7), CANMET (23.3) |
| 3.41.1a | In-situ Treatment of AMD | 41 | 41 | 0 | MOEE (30), Falconbridge (30) |
| | | | | | |
| 5.2.1a-c | Communications Plan - CIMM Lectures, Brochure, TV Series | 5 | 0 | 5 | CANMET (5) |
| 5.2.1d | Communications Plan - Video | 150 | 127 | 23 | Ontario (75), CANMET (75) |
| 5.4.2 | AMD/ARD Handbook | 150 | 0 | 150 | Ontario (75), CANMET (75) |
| 5.7.1 | MEND Newsletter | 3 | 3.5 | (0.5) | CANMET (3.5) |
| | | | | | |
| 6.2 | New Ideas - Wrap Up | 95 | 89.4 | 5.6 | C.B.D.C. (10), CANMET (30), Québec (20), Env. Can. (10), Ontario (25) |
| | Totals | 3,725 | 2,178 | 1,543 | 95/04/02 |

## Table 5: Projects Recommended for Board Approval

| Project | Title | Proposed Budget ($000's) | Funds Required ($000's) | Commitments/Comments ($000's) |
|---|---|---|---|---|
| 1.16.3 | Critical Evaluation of Chemical Test Procedure | 30 | 0 | Env. Can (20), HBM&S (10) |
| 1.16.4 | Evaluation of Static and Kinetic Test Procedures | 27 | 0 | Gibraltar (7), Placer Dome (4), Cominco (3), Teck (7) |
| 1.16.5 | Qualitative Factors in Static Tests | 50 | 50 | |
| 1.18.1a | Information System for Static Tests | 50 | 50 | |
| 1.27.1a | Guide for Predicting Water Quality from Waste Rock Dumps | 35 | 0 | CANMET (17.5), B.C. (17.5) |
| 1.41.3a | Waste Rock Monitoring - Ontario, Phase I | 30 | 0 | CANMET (15), Ontario (15) |
| 1.41.3b | Waste Rock Monitoring - Ontario, Phase II | 305 | 0 | CANMET (115), Ontario (115) INCO (?) |
| 1.41.4 | Waste Rock Monitoring - Low Acid Potential | 200 | 200 | |
| 1.44.1 | Waste Rock Disassembly - B.C. | 35 | 0 | Homestake (35) |
| 1.61.1 | Permafrost - Technical Review | 32 | 0 | DIAND (32) |
| 1.61.2a | Permafrost - Acidic Drainage Prevention and Control | 50 | 0 | DIAND (50) |
| 1.61.2b | Cullaton Lake Data Analyses and Interpretation | 10 | 0 | Homestake (10) |
| 2.11.1e | Peer Review of Subaqueous Disposal of Tailings - Phase II | 30 | 0 | CANMET (30) |
| 2.11.5b | Shallow Water Covers - Equity Silver (for reapproval at higher costs $195k vs $80k) | 115 | 15 | CANMET (100) |
| 2.12.1b | Man-made Lakes - Louvicourt Project (for reapproval at higher cost - $496 vs $350k) | 469 | 0 | CANMET (315), Teck (106), Aur (48) |
| 2.15.2 | Metal Release after Flooding | 200 | 200 | |
| 2.17.1 | Use of Elevated Water Table to Reduce and Control AMD | 50 | 0 | CANMET (25), Ontario (25) |
| 2.21.3 | Peer Review of Waite Amulet and Heath Steele Soil Covers Scope increase | 17 | 0 | (Cominco (47) approved project), CANMET (20) |
| 2.22.2b | Evaluation of Dry Covers Built from Mine Tailings - Field | 200 | 0 | Québec (67), Itec (67), CANMET (67) |
| 2.23.3b | Design Parameters for Pervious Envelope and Porous Surround | 25 | 0 | Ontario (25) |
| 2.25.3 | Assessment of Alternate Materials for Dry Covers | 280 | 0 | Falconbridge (140), Ontario (70), CANMET (70) |
| 2.31.1c | Additional Monitoring of Heath Steele Cover on Waste Rock | 50 | 0 | Brunswick Mining (25), CANMET (25) |
| 2.36.3 | Review of Methods for Characterizing Waste Rock Before Disposing Under Water | 30 | 30 | |
| 2.37.1 | Layering of Waste Rock to Prevent ARD | 50 | 50 | |
| 2.37.2 | Review of Methods to Prevent the Onset of ARD | 50 | 50 | |
| 2.37.3 | Characterization of Test Materials from Samatosum Study | 35 | 35 | |

*Table 5: Projects Recommended for Board Approval Continued...*

| Project | Title | Proposed Budget ($000's) | Funds Required ($000's) | Commitments/Comments ($000's) |
|---|---|---|---|---|
| 3.41.2 | Metal and Sulphide Surface Biomineralization | 20 | 0 | Env. Can. (20) |
| 3.42.2 | Lime Sludge Stabilization, Disposal and Use | 105 | 105 | |
| 4.5.4 | Environmental Monitoring Handbook for Acidic Drainage | 80 | 0 | Ontario (40), CANMET (40) |
| 4.6.5a | Technique for Oxygen Flux at Tailings Surface | 11 | 0 | INCO (11) |
| 4.6.5b | Field Demonstration for Oxygen Flux | 15 | 0 | INCO (15) |
| 5.1.2 | Workshops (redirection of New Ideas Funds) | 30 | 0 | Various funders |
| 5.6.3 | Fourth International Conference on Acidic Drainage | 80 | 60 | BC (20) |
| 5.7.2 | CDROM Publication of MEND Reports | 80 | 80 | |
| | Totals | 2,876 | 925 | |

95/04/02

## Table 6: 1995 MEND Program and Budget

| Committee | Program Research Plan ($000's) | Budget: Committed ($000's) | Revised Spent & 1995 ($000's) | Proposed 1995 ($000's) | Committed ($000's) | Needed | Area |
|---|---|---|---|---|---|---|---|
| | | - Approved - | | | - Proposed - | | |
| Prediction | Chemical Prediction | 1,314 | 1,165 | | 157 | 57 | 100 |
| | Modelling | 1,932 | 1,222 | | 35 | 35 | 0 |
| | Waste Rock Knowledge | 957 | 294 | | 570 | 370 | 200 |
| | Permafrost | 0 | 0 | | 92 | 92 | 0 |
| | **SUB-TOTAL** | **4,203** | **2,681** | | **854** | **554** | **300** |
| Prevention & Control | Underwater Disposal | 1,393 | 1,291 | | 614 ** | 589 | 25 |
| Wet Barriers | | 1,955 | 1,963 | 250 | 50 | 200 | |
| | Dry Barriers | 2,673 | 1,595 | | 497 | 497 | 0 |
| | Waste Rock | 2,110 | 1,590 | | 215 | 50 | 165 |
| | Other | 1,150 | 947 | | 25 | 25 | 0 |
| | **SUB-TOTAL** | **9,281** | **7,384** | | **1,601** | **1,211** | **390** |
| Treatment | | **1,729** | **1,229** | | **125** | **20** | **105** |
| Monitoring | | **1,125** | **950** | | **106** | **106** | **0** |
| Technology Transfer | | **362** | **615** | | **190** | **50** | **140** |
| New Ideas & Innovation | | **1,300** | **250** | | **0** | **0** | **0** |
| **TOTALS** | | **18,000** | **13,109** * | | **2,876** | **1,941** | **935** |

* Includes $80,000 in unfunded projects

** Includes $323,000 approved in 1994 for Louvicourt Project

## 1.0 Introduction

The **Prediction committee**, with a new chairman and Secretariat co-ordinator, has a renewed focus and approach for developing a toolbox of information to predict and prevent AMD in Canada. A significant amount of research has been completed for mine tailings, in and outside of MEND. The fundamental characteristics of tailings, in terms of mathematical prediction, are well understood when compared to waste rock. For that reason, the majority of the remaining work aimed at developing predictive tools will focus on waste rock.

The elusive comprehensive predictive model for waste rock, originally a primary focus, is now recognized to be unachievable within the MEND envelope. A comprehensive model may not even be practical for a wide range of sites.

The remainder of the MEND program will be spent filling in the knowledge gaps in three major areas. A greater understanding of the fundamental characteristics of the components of AMD/ARD will be the targeted result. These three areas are: waste rock basic knowledge, which will focus on waste rock pile chemistry and physics, chemical predictive techniques; and, permafrost. Empirical modelling approaches are also being developed as predictive tools to determine the long term acid generating capabilities of operating waste rock piles. Each of these areas and the associated projects are described below.

## 1.1 Chemical Prediction

Accomplishments
The first step towards a reference material was completed via an interlaboratory program with NBM-1. A bimodal distribution of NNP results was evident from the project and therefore a provisional value for NNP of 42±9 tonnes $CaCO_3$/1000 tonnes was released. The material is available for quality control, method development or comparison of protocols.

Activity
Continuation of the DBARD project has resulted in the transfer of the database to a Windows based platform. Data input is expected for the remaining year of the project. The Evaluation of Scaling project is nearly complete. A Climatic Controls project is not being actively pursued and has been temporarily removed from Prediction.

Future Direction
The primary focus in the area of chemical prediction is the relationship between laboratory chemical predictive tests and data collected in the field. This will add credibility to the results obtained by static and kinetic tests commonly employed in the Canadian mining industry. Mineralogy is also being examined in the context of its effect on acid-base accounting (ABA) results. It is appreciated that current static test methods are ambiguous and often rely on qualitative observations to yield quantitative information which is routinely used in decision making processes related to mine waste management. In this regard, the qualitative components of a static test method will be examined in an attempt to remove these ambiguities and establish a rigorous protocol with which mining

companies and regulators may have increased confidence. Subsequently, additional NNP certified reference materials may be produced using the procedure as a template to increase the precision of interlaboratory test data.

The interpretation of static test data is often a difficult and time-consuming task since other data such as chemical analysis, mineralogy, sulphur speciation etc. must be considered in the final analysis. This frequently necessitates the assistance of numerous experts in the field to establish a valid conclusion. To simplify this process, an information system to take into account ABA, chemical and mineralogical data as a minimum, and recommend to operators the necessary steps required to minimize the risk associated with ARD will be developed.

The Chemical Prediction Work Plan is shown in Figure 3. The individual projects are listed in Table 7.

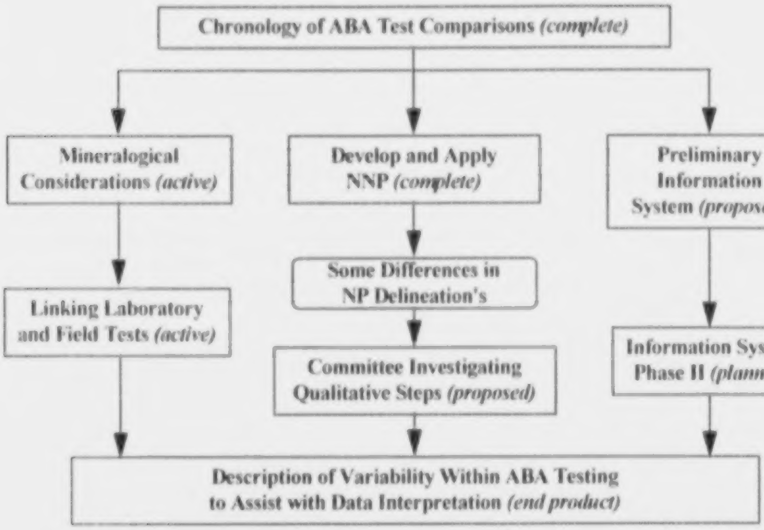
Table 7: Chemical Prediction

| **Completed** | | **Budget($)** |
|---|---|---|
| 1.11.1 | AMD from Waste Rock - Literature Review | 50k |
| 1.12.1a | Compile AMD Prediction Data (DBARD) | 45k |
| 1.14.1 | Field Evaluation Rock Hydrochemistry - Mine Doyon | 450k |
| 1.15.1a | AMD from Open Pits - Equity Silver | 53k |
| 1.16.1a | Evaluation of Predictive Techniques | 63k |
| 1.16.1b | Manual of Chemical Evaluation Procedures | 23k |
| 1.16.1c | Development of Static Evaluation Procedures | 21k |
| 1.16.2 | Interlaboratory Program for Standard Material NBM-1 | 20k |
| 1.17.1 | Hydrogeochemical Investigations - Waite Amulet 1985/90 | 285k |
| 1.19.1 | Kinetic Tests for Cinola Gold | 94k |
| **Active** | | |
| 1.12.1b | DBARD - Continuation | 40k |
| 1.19.2 | Evaluation of Scaling - Bench, Pilot and Field Scale | 21k |
| **Recommended** | | |
| 1.16.3 | Critical Evaluation of Procedures to Determine the Potential of Mining Wastes to Produce Acid Rock Drainage | 30k |
| 1.16.4 | Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data for Selected Mine Sites | 27.2k |
| 1.16.5 | Identification of Qualitative Factors in Standard Static Prediction Test Protocols | 50k |
| 1.18.1a | Development of an Information System to Assist with the Interpretation of Static Acid-Base-Accounting Test Data | 50k |

| | |
|---|---|
| **Total** | **1,322k** |

**Figure 3: Chemical Prediction Work Plan**

**Comment:** Figure 3 goes here


Chronology of ABA Test Comparisons *(complete)*
Mineralogical Considerations *(active)*
Develop and Apply NNP *(complete)*
Preliminary Information System *(proposed)*
Some Differences in NP Delineation's
Linking Laboratory and Field Tests *(active)*
Committee Investigating Qualitative Steps *(proposed)*
Information System Phase II *(planned)*
Description of Variability Within ABA Testing to Assist with Data Interpretation *(end product)*

## 1.2 Waste Rock Knowledge

Accomplishments

The final report (1.51.1) on chemical and biological kinetics reviews and critically analyzes several experimental and theoretical results on chemical, physical and biological aspects of pyrite oxidation. Based on available information a kinetic model in the form of coupled non-linear ordinary differential equations was constructed for the coupled chemical reactions responsible for ARD. Computer simulations were performed based on these equations. The results suggest that the chemical reactions involved in pyrite oxidation do not produce chaotic behaviour or other types of chemical oscillations. The report on non-linear modelling (1.51.2) agrees that no chemical chaos exists in the pyrite oxidation, but suggests that the effect of physical processes may have a greater effect on the predictability of acid rock drainage problems. The latter report suggests that physical transport processes in waste rock piles need to be addressed.

Activity

The Mine Doyon Peer Review is designed to examine all project reports to date related to the waste rock study at Mine Doyon and to present specific recommendations for further research, monitoring or other work, in the context of current waste rock prediction capabilities.

A M.Sc. project at UBC (1.31.2) is attempting to develop the probable mechanisms that relate bulk mineralogy to the secondary products formed through the identification and characterization of weathering products retained in a waste rock pile from a dump-leach mine site. Estimations of the reactivity/stability of these secondary products under differing environmental conditions are also being made. The applicability of detailed lithological and mineralogical characterization to the prediction of acid rock drainage is being addressed through a Ph.D program at UBC (1.32.1). The projects are slated for completion in late summer of 1995 and mid-1996, respectively.

Future Direction

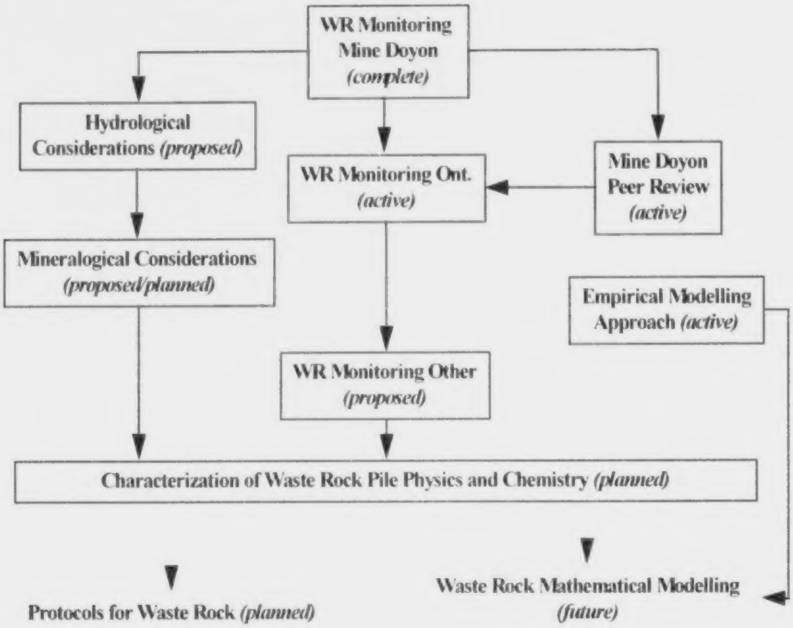
Part of the problem related to the development of a comprehensive model for waste rock is the lack of a fundamental understanding of the basic physical and chemical processes occurring in a waste rock pile. The Mine Doyon project yielded a wealth of information, yet it is recognized that additional information from other waste rock piles is necessary to establish a solid knowledge base of waste rock pile information. In this regard, three distinct projects are proposed. Two waste rock pile monitoring projects are recommended. One of these is directed at a relatively new waste rock pile in Ontario which is currently acid generating. The second site has yet to be determined but will be a waste rock pile that either has not begun to generate acidic drainage or generates low fluxes of acidic drainage. A third project, to qualitatively examine the hydrogeology of a waste rock pile and to examine, quantitatively, the chemistry of stored reaction products, is also proposed. In this fashion the difficulties associated with the coupling of chemistry and physics in the waste rock pile may be considered. An associate project is examining theoretical aspects of hydrogeology of waste rock piles. The projects related to this area are presented in Table 8. The Waste Rock Knowledge Work Plan is shown in Figure 4.

Table 8: Waste Rock Knowledge

| | | Budget($) |
|---|---|---|
| **Completed** | | |
| 1.31.1 | Study of Weathering Employing SIMS | 99k |
| 1.32.1 | Geological and Mineralogical Approach to ARD Prediction | 73k |
| 1.51.1 | Quantitative Analysis of Chemical and Biological Kinetics | 12k |
| 1.51.2 | Non-linear Modelling of Chemical Kinetics for AMD | 30k |
| **Active** | | |
| 1.31.2 | Residual Weathering Products in Waste Rock Dumps | 40k |
| 1.32.2 | Pyrite Oxidation - Lithological & Mineralogical Approach | 40k |
| **Recommended** | | |
| 1.41.3a | Waste Rock Pile Monitoring Ontario - Phase I | 30k |
| 1.41.3b | Waste Rock Pile Monitoring Ontario - Phase II | 305k |
| 1.41.4 | Waste Rock Pile Monitoring - Low Acid Production (Borderline) | 200k |
| 1.44.1 | Waste Rock Pile Disassembly - B.C. | 35k |
| | **Total** | **864k** |
| Associate | Waste Rock Hydrogeology - B.C. | |

**Figure 4: Waste Rock Knowledge Work Plan**

**Comment:** Figure 4 goes here


WR Monitoring Mine Doyon (complete)
Hydrological Considerations (proposed)
WR Monitoring Ont. (active)
Mine Doyon Peer Review (active)
Mineralogical Considerations (proposed/planned)
Empirical Modelling Approach (active)
WR Monitoring Other (proposed)
Characterization of Waste Rock Pile Physics and Chemistry (planned)
Protocols for Waste Rock (planned)
Waste Rock Mathematical Modelling (future)

## 1.3 Permafrost

Future Direction

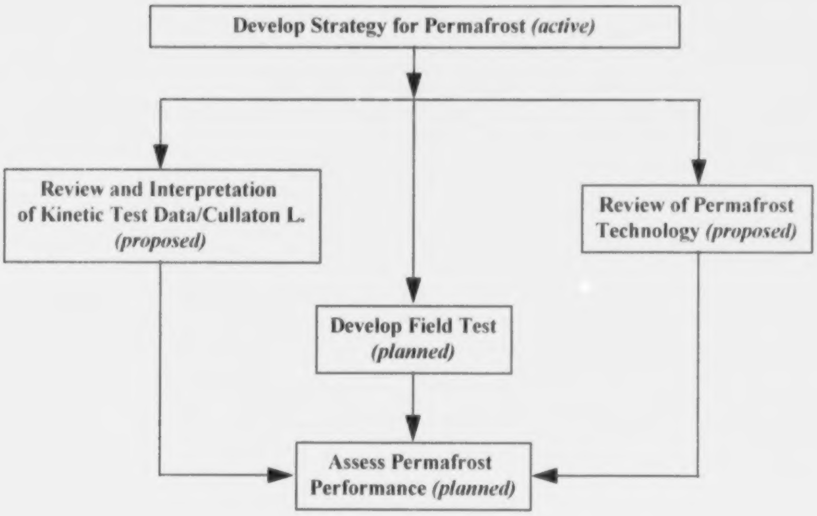
This research area is a new program area under **Prediction** with intimate ties to **Prevention & Control** and was developed by both committees. The aim of this new area is to determine the feasibility of employing permafrost as a disposal option for mine wastes in northern climates. Literature reviews of all permafrost related engineering and environmental publications will be followed by the design and field testing of proposed permafrost strategies for waste management. The influence of cold climates on the rate of ARD production and the concomitant effect on microbiology is also proposed. Three projects are listed in Table 9 while two other projects addressing the design and testing of strategies are planned for the future. The general strategy for permafrost is shown in Figure 5.

Table 9: Permafrost

| | | |
|---|---|---|
| **Recommended** | | |
| 1.61.1 | Permafrost Technical Review | 32k |
| 1.61.2a | Acid Rock Drainage (ARD) Prevention and Control: Towards a Tailings and Waste Rock Strategy for Using Permafrost to Manage ARD | 50k |
| 1.61.2b | Permafrost - Cullaton Lake Data Analysis and Interpretation | 10k |
| | **Total** | **92k** |

**Figure 5: Permafrost Work Plan**

**Comment:** Figure 5 goes here


Develop Strategy for Permafrost (active)
Review and Interpretation of Kinetic Test Data/Cullaton L. (proposed)
Review of Permafrost Technology (proposed)
Develop Field Test (planned)
Assess Permafrost Performance (planned)

### 1.4 Modelling

Accomplishments

The second phase of the Mine Doyon work is complete. Physical parameters such as climatic data, temperature profiles within the dump, total discharge of acid drainage from collecting ditches and chemical composition of the effluents were monitored on a regular basis. From the information collected, geochemical, physical and hydrologic simulation capabilities are being developed. The data collected were presented in a series of seven topic specific reports from November 1992 to March 1994 including a summary report completed in June of 1994.

Numerical simulations using ANTSO's FIDHELM model indicated that gas transport is dominated by diffusion at the Heath Steele site. Modelling of the waste rock pile with the soil cover in conjunction with field data indicates that the soil cover is effective to reduce the ingress of oxygen.

The ARD waste rock database was implemented in Paradox for Windows and includes details of the monitoring program such as: the parameters measured, the methods and instrumentation used, the temporal and spatial extent of measurements, and any data analysis or modelling done as well as a summary of any conclusions drawn.

Activity

The complexity of the MINEWALL II model has resulted in enormous amounts of computer code which cannot be handled by the current DOS-based programming language (Visual Basic). After consultation with the Prediction committee, the contractor will simplify the computer code to retain user-friendliness without simulation of complex scenarios. The model should be complete by March 1995.

The geochemical reviews project divided existing geochemical models into five classes. These classes are: equilibrium thermodynamic models, mass transfer models, coupled mass transport-mass transfer models, supporting models, and empirical and engineering models. Each class of geochemical models can be viewed as addressing a different type of ARD prediction objective. These models are presented in a table format for easy comparison of features. The project will be completed by the end of March 1995.

Future Direction

As mentioned earlier, the development of a comprehensive model for tailings or waste rock is not feasible with the current level of understanding of the basic chemical and physical phenomena occurring. However, the feasibility of employing seepage data to estimate the future rates of metal release to the environment is being addressed. The 'empirical' modelling approach has seen success with limited waste rock seepage data and it is proposed to verify and further refine this method.

Alternative statistical-analytical methods to define trends in seepage data and imply mechanistic effects are also being addressed.

**Table 10: Modelling**

| **Complete** | | **Budget($)** |
|---|---|---|
| 1.21.1a | Evaluate RATAP.BMT2 Capabilities | 30k |
| 1.21.1b | Workshop on Modelling Techniques | 73k |
| 1.21.1c | Prepare RATAP User's Manual | 19k |
| 1.24.1 | Development of Preliminary Waste Rock Modelling | 21k |
| 1.25.1 | Soil Atmosphere Flux Model to Design Tailings Covers | 56k |
| 1.26.1 | Development of Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock | 90k |
| 1.14.2 | Mine Doyon Phase II - Monitoring & Modelling | 450k |
| 1.15.2 | AMD From Open Pits-Expansion/Verification of Model | 88k |
| 1.22.1 | ANSTO Model at Heath Steele | 145k |
| 1.41.1 | International Workshop on Waste Rock Modelling | 8k |
| 1.41.2 | ARD Waste Rock Monitoring Database | 22k |
| **Active** | | |
| 1.42.1 | Critical Review of Geochemical Modelling | 60k |
| 1.14.3 | Mine Doyon - A Comprehensive Review | 60k |
| 1.21.2 | Pyrrhotite Oxidation - Laboratory & Modelling Studies | 100k |
| **Recommended** | | |
| 1.27.1 | Guide for Predicting Water Chemistry from Waste Rock Dumps | 35k |
| | **Total** | **1,257k** |

## 2.0 Introduction

Twelve **Prevention and Control** (P&C) projects were completed in 1994 and at year end 13 additional projects were underway. To manage many activities more effectively, the P&C committee has sub-divided its research programs into five main areas: underwater disposal, wet barriers, dry barriers, waste rock and others. Prevention and Control is on track to deliver outputs listed in the 1992 Research Plan by the end of 1997 or early 1998. During the next 3 years closer integration of projects with Prediction and Technology Transfer will take place.

## 2.1 Underwater Disposal

Early in the MEND program, consensus had been developed that placing acid-generating materials underwater would prevent sulphide oxidation (underwater disposal is defined as the placement of fresh, unoxidized tailings underwater).

A work plan was developed in 1989, which consisted of evaluating four lakes where tailings had been placed. A preliminary evaluation and geochemical assessment on the interstitial water was completed (2.11.1 a,b and c) over two-year periods for each lake (Table 11).

At the request of the MEND Board of Directors, a scientific and technical peer review (2.11.1d) of all work done was completed in 1992. This and presentations made to regulatory agencies provided feedback on the merits of use of subaqueous disposal to control reactive materials. Information deficiencies were also documented. A planning team of technical and scientific experts met in January 1993 and outlined a program which incorporated the peer review recommendations.

The planning committee has focused on field and analytical techniques to improve measurement of metal fluxes at the sediment/water interface and to clarify understanding of the reactivity of the substrate. Two lakes were selected to obtain additional geochemical data for the study: Buttle Lake in British Columbia as a deep lake and Anderson Lake in Manitoba as a relatively shallow site, where tailings were actively being deposited.

Three major field campaigns were conducted in 1993 - two on Anderson Lake and one on Buttle Lake. The basic elements of the original hypothesis have been successfully addressed, as the reactivity of the tailings studied in the 1993 programs has been demonstrated to be low. In addition, although not studied in detail, biological communities have been demonstrated to be disturbed or in the process of reestablishment in the studied lakes. Companion studies included technical literature review (metal toxicology - 2.11.2a), comparison of field techniques, and the establishment of quality assurance and quality control programs.

In 1994, an assessment of mine-related inputs to Anderson Lake was carried out (2.11.3c) to determine, as much as possible, the extent of relationships between the various discharges and observed historical changes in lake chemistry. All available records over a 25-year period when the lake received mine effluents and tailings were collected and interpreted. The most significant changes occurred immediately subsequent to tailings deposition.

Scientific and regulatory review and planning is a major part of the program, and is assisting in achieving a fair and objective study of the concept and methodology for subaqueous disposal of reactive tailings in lake. The committee recommends that a second peer review (2.11.1e) be carried out to assess the work undertaken over the past three years considering the original points of concerns identified in the first peer review (2.11.1d).

**Table 11: Underwater Disposal Projects**

| **Completed Projects** | | **Budget($)** |
|---|---|---|
| 2.11.1a | Evaluation of Existing Underwater Disposal Sites - 1988/89 Program | 220k |
| 2.11.1b | Evaluation of Existing Underwater Disposal Sites - 1990 Program | 136k |
| 2.11.1c | Evaluation of Existing Underwater Disposal Sites - 1991/92 Program | 67.6k |
| 2.11.1d | Peer Review on the Subaqueous Disposal of Tailings | 34.4k |
| 2.11.2a | Literature Review Report: Metal Toxicology | 16.3k |
| 2.11.3ab | Evaluation of Underwater Disposal Site - Anderson Lake | 400k |
| 2.11.3c | Historical Assessment of the Mine-related Inputs to Anderson Lake, Manitoba | 10k |
| **Active Projects** | | |
| 2.11.4a | Evaluation of Underwater Disposal Site - Buttle Lake | 250k |
| 2.11.5a | Shallow Water Covers - Equity Silver | 80k |
| 2.11.9 | Underwater Disposal Sites - Design Criteria | 50k |
| 2.12.1ab | Man-Made Lakes Disposal Sites - Louvicourt Project | 350k |
| **Recommended for 1995** | | |
| 2.11.1e | Peer Review on the Subaqueous Disposal of Tailings - Phase II | 30k |
| 2.11.5b | Shallow Water Covers - Equity Silver (increase in scope) | 115k |
| 2.12.1b | Man-Made Lakes Disposal - Louvicourt (increase in scope) | 146k |
| | **Total** | **905.3k** |
| **Associate Project** | | |

Study of Submarine Ocean Tailings Disposal

Completed work has demonstrated that subaqueous disposal is justified technically. Design and operating criteria for an application manual commenced in 1994 with a case study at the Equity Silver site. Phase I is the collection of the key physical and chemical variables of the disposal system and Phase II, scheduled for 1995, is the field component. Using the Equity site to illustrate the dynamics of several of the key physical variables will lead to the start of the development of both operational and closure guidelines (2.11.9) for subaqueous disposal of tailings. Additional funds are needed to complete a detailed field program and the committee recommends expanded funding approval.

Underwater disposal of mine wastes in man-made lakes is presently an option favoured by the mining industry to prevent the formation of acidic drainage. Because of the potential controversy associated with using natural lakes for subaqueous disposal, there is considerable interest in evaluating whether artificial basins offer similar advantages to natural lakes. In 1994, the detailed conceptual design for a field monitoring and laboratory program at the new Louvicourt Mine in northwest Québec was completed (2.12.1a). In 1995 the integrated laboratory and field programs will commence. The detailed design for the Louvicourt project has resulted in an increase in scope which is recommended for approval.

The overall Underwater Disposal program is shown diagrammatically in Figure 6.

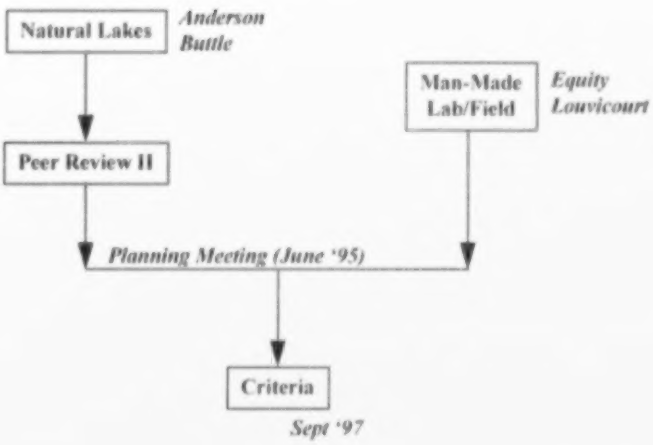


**Figure 6: Underwater Disposal**

Comment: Figure 6 goes here

## 2.2 Wet Barriers

As distinct from underwater disposal, wet barriers refers to establishing a water cover on oxidized tailings. As with underwater disposal, continued oxidation is considered unlikely but the mobilization of the soluble salts becomes an important consideration.

The proposed closure plans for several Canadian tailings sites call for water covers. Monitoring of the 65 hectares experimental test site and the laboratory columns at Quirke Lake was completed in 1994. Reports from Rio Algom (e.g. geotechnical aspects, design recommendations and construction drawings, hydrogeologic, water chemistry) will be available in 1995. The draft reports by CANMET summarizing the laboratory studies are being reviewed by Rio Algom before being released through MEND.

Research into the effects of flooding tailings was completed at the Solbec Cupra site in 1994. Three reports are available: a synopsis of all collected data since 1989; a second on the optimum height of water required to prevent the resuspension of solid particles; and the results of a study on the chemical and microbiological effects of flooding. As a result of these projects and economic evaluations, flooding of the site was initiated in 1994. A contract to monitor the effects of flooding has been put in place (2.13.2d).

The feasibility study of flooding the Falconbridge "New Tailings" site was also completed in 1994. It was predicted that flooding the site would result in long term treatment costs because of the mobilization of stored oxidation products in the tailings thus reducing the benefits associated with flooding. With this in mind, Falconbridge is investigating the possibility of using municipal solid waste compost and/or other organic materials as covers for the higher elevated areas (2.25.3) and flooding of the low lying areas (Table 12).

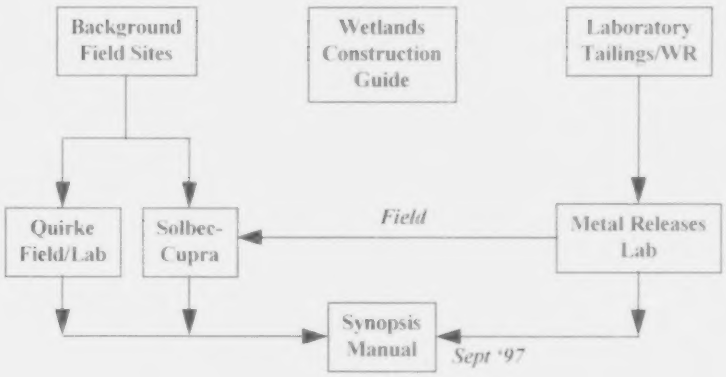
Work continued on the laboratory and field test program (2.15.1) to simulate the movement of total acidity and metal loadings from oxidation products under different flow regimes and to predict treatment requirements. Covering sulphitic mine tailings with water effectively reduces oxygen influx to the tailings and the resulting acid generation. However, metals present in porewater solutions or in soluble mineral phases may still be released from the flooded tailings impoundment. It has also been shown that upward fluxes can be limited by placing a layer of material on the tailings surface (acts as a precipitation-sorption layer to impede metal transfer). It is recommended that further work be carried out on the geochemical processes which influence metal releases (2.15.2). Possible barrier materials that could be used to prevent upward fluxes to the surface cover will also be investigated. The construction costs for artificial hydraulic containment structures to obtain an adequate water storage over the tailings are always high. It is therefore recommended, before deciding to commit to these costs, to evaluate treatment and maintenance requirements using laboratory and field testing. This project will help define some of the costs associated with flooding of oxidized tailings. The Surface Flooding work plan is shown in Figure 7.

Table 12: Wet Barriers Projects

| Completed Project | | Budget($) |
|---|---|---|
| 2.13.1 | Flooding of Existing Tailings Sites - Quirke Lake | 835k |
| 2.13.2abc | Flooding of Existing Tailings Sites - Solbec Cupra | 291k |
| 2.13.3 | Flooding of Existing Tailings Sites - Falconbridge | 170k |
| 2.14.1 | Establish Vegetative Wetlands Over Tailings | 30k |
| **Active Projects** | | |
| 2.13.2d | Monitoring of the Flooded Solbec Cupra Tailings Site | 150k |
| 2.15.1 | A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites | 487k |
| **Recommended for 1994** | | |
| 2.15.2 | Metal Releases after Flooding | 200k |
| 2.17.1 | Use of Elevated Water Table as a Method to Reduce AMD | 50k |
| | **Total** | **2,213k** |
| **Associate Projects** | | |
| | Flooding of Existing Tailings Sites - Stekenjokk, Sweden | |

## Figure 7: Surface Flooding

**Comment:** Figure 7 goes here



Disposal options and the feasibility of using artificial methods to raise the phreatic surface above the reactive materials need to be evaluated technically and economically as a method of reducing acid production. If the fluctuating phreatic surface can be kept above the sulphides, this could provide a good, economical abandonment strategy for the mining industry. The primary goal of the project is obtaining an increased knowledge base with respect to the state-of-the-art for the option of creating an elevated water table to control acidic drainage. Approval is being requested to complete this evaluation.

## 2.3 Dry Barriers

The use of dry barriers to prevent further oxidation and/or transportation of oxidation products, has been the subject of considerable discussion in 1994. This follows a decision by the Management committee at a February meeting that dry covers research should be a low priority due to the high costs of application and maintenance. However, the MEND Board directed the Management and P&C committees to re-examine this issue for possible work in the future. The main emphasis for dry barriers research projects is that the results must have significant cost-saving potential for Management to consider accepting the project in MEND.

The dry barriers at both Waite Amulet and Heath Steele have thus far proven very effective. The cost of the covers is the drawback and lower costing materials or methods of construction must be found for this option to be widely used. Cost-benefit analyses for some materials to be used for construction of dry covers makes dry barriers appear uneconomical, but for many inactive tailings and waste rock sites, dry barriers may be the only option available other than perpetual treatment. The committee agrees that there is a need for the development of affordable dry barriers technology and future research should be directed on priority materials identified in the alternate cover materials project (Table 13).

While dry covers do reduce the penetration of oxygen and/or water into the tailings, they may be too expensive, too short term or the needed materials may not be locally available. A study to prepare a ranking of the potential alternate cover materials that could be further considered was completed in 1994 (2.20.1). The review has also brought to light several yet unresolved concerns such as: the long-term effectiveness of dry covers as oxygen barriers, the net impact on the rate of oxidation of reactive tailings; poor availability of dry cover material in some locations; prohibitive cover construction costs for untrafficable areas; and effluent quantity and quality and its impact on the receiving environment. The potential materials given a high priority by the MEND study include natural soils, modified soils, desulphurized tailings, tailings slimes, wood waste, and paper mill sludge.

The cover materials evaluated to date in laboratory and in companion field studies include composite clay/soil covers and plastic membranes (Waite Amulet). A laboratory project is evaluating fine tailings as an alternative material to replace clays or low permeability soils that are not available at many sites. The aim of properly designed composite or layered covers is to maintain a saturated layer which prevents the transfer of oxygen. It has been found that these covers also effectively limit water transport through the cover. Many recommendations for additional research work were proposed for the natural soil covers but the committee decided that prior to additional work being carried out, a peer review on the work to date should be completed. A contract was signed in December 1994 (2.21.3). Several items were recommended for inclusion in the peer review which should result in a more comprehensive review of covers in general. This increase in scope is recommended for approval by the committee. If the peer review is favourable, a set of design and construction protocols for soil covers (2.21.4) will be prepared.

**Table 13: Dry Barriers Projects**

| **Completed Projects** | | **Budget($)** |
|---|---|---|
| 2.20.1 | Evaluation of Alternate Dry Covers for the Prevention of Acid Mine Drainage from Tailings | 55k |
| 2.21.1 | Engineering Dry Covers for Tailings - Laboratory | 216k |
| 2.21.2 | Engineered Dry Covers for Tailings - Noranda | 533k |
| 2.22.1 | Assessment of Hardpan | 101k |
| 2.23.1 | Documentation of Disposal Methods - Tailings and Waste Rock | 75k |
| 2.24.1 | Vegetation Manual | 34k |
| 2.25.1 | Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost | 86k |
| 2.25.2 | Design of an Organic Barrier Using Wood Waste - East Sullivan | 210k |
| **Active Projects** | | |
| 2.21.3 | Peer Review of Waite Amulet and Heath Steele Soil Covers | 20k |
| 2.21.4 | Protocols for Engineered Dry Covers over Tailings and Waste Rock | 30k |
| 2.22.2a | Evaluation of Dry Covers Built from Mine Tailings | 235k |
| **Recommended for 1995** | | |
| 2.21.3 | Peer Review of Waite Amulet and Heath Steele Soil Covers (increase in scope) | 20k |
| 2.22.2b | Evaluation of Dry Covers Built from Mine Tailings - Field | 200k |
| 2.25.3 | Assessment of Alternate Materials for Dry Covers for Reducing AMD | 280k |
| | **Total** | **2,095k** |
| **Associate Project** | | |

Engineered Dry Covers for Tailings - Curragh
Evaluation of Dry Covers Built with Mine Tailings - Field ($400k)
Assessment of Alternate Materials for Dry Covers for Reducing AMD ($254k)

An analysis by the committee has shown that dry covers built from more than one layer of tailings deposited hydraulically has potential merit for saving costs. A $600k laboratory and field study using fine tailings in covers was proposed to the committee. The laboratory portion, $200k, will result in a rational design process that could be used at different locations when only basic information (e.g. grain size, mineralogy) are known and the committee recommends its approval. The field component ($400k) proposes to use mechanical placement of the cover materials thus increases cost associated with placement. The committee recommends that this part of the project be accepted as an associate project.

Two other projects evaluating organic type covers (compost and wood waste) that are oxygen consumers which may function to limit oxygen penetration but not water penetration were completed in 1994. The conclusions of the compost project were based on a relatively short term laboratory experiment and this study should be seen as a preliminary look at compost cover layers and their design as a tailings cover to prevent AMD. The results demonstrated that a 1m wood waste cover effectively blocks access of oxygen which could oxidize underlying sulphates, as shown by the fact that methane is generated. Formation of an iron sulphide precipitate near the compost cover layer-tailings interface is a strong indication of reversal of AMD processes. Comprehensive, long term laboratory pilot scale work should now be done and is recommended (2.25.3) to follow up on the potential benefits that were identified for organic type materials. An economic evaluation, recognizing the practical and regulatory conditions in Ontario, suggests that utilizing organic type materials for covers has both practical and economic justification for both the mining industry and for the major source of the organics - municipalities. The Dry Barriers program is shown in Figure 8.

**Figure 8: Dry Barriers**

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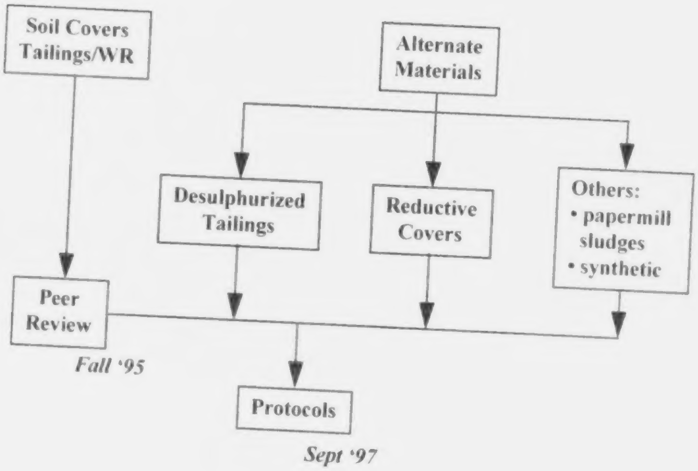

Soil Covers Tailings/WR
Alternate Materials
Desulphurized Tailings
Reductive Covers
Others:
• papermill sludges
• synthetic
Peer Review
Fall '95
Protocols
Sept '97

## 2.4 Waste Rock

Although some of the cover techniques available for tailings may be applicable to waste rock, the circumstances and methods of application are different. Waste rock piles have higher potential for developing induced air flows due to temperature gradients, porosity and differential settlement in the piles. The Waste Rock work plan is shown in Figure 9.

Monitoring of the Heath Steele composite clay/soil cover continued in 1994. The results clearly indicate reductions in the gaseous oxygen concentrations in the pile. Initial concentrations of 20%, prior to cover placement, have been reduced to about 1%. Pile temperatures decreased following cover placement, but now appear to be controlled primarily by climatic conditions, rather than oxidation rates. Of critical importance for evaluating the effectiveness of the soil cover, is the results of water chemistry from seepages emanating from the pile. The unique design of the cover allows a full water balance to be calculated. This has shown an infiltration rate of about 2% of precipitation. However, the water quality of the effluent has not significantly changed, and it is recommended that this be further investigated by continuing the monitoring for two more years (2.31.1c). It is hoped that additional monitoring will allow the transition period for the oxidized waste rock to be defined. The physical integrity of the system will also be studied (Table 14). The Heath Steele project will also be a subject of the peer review on natural soil covers (2.21.3).

Monitoring of the cementitious cover at Westmin continued in 1994. Some superficial hairline cracks formed during the curing period but have not expanded after two winters. Some cracks have penetrated through the cover and work is progressing to see how much moisture has reached the waste rock. No new cracks have been found as a result of the freeze/thaw cycles. The study indicates that shotcrete dry covers can be a viable option for sealing prepared waste rock piles. The study did not evaluate the effectiveness of the cover in restricting acid generation. The final monitoring report is due in 1995. No further work in cementitious covers is recommended and the technology will also be reviewed in the peer review (2.21.3).

In 1994 a study at Noranda Technology Centre continued to evaluate several waste rock management techniques in lysimeters specially constructed for this purpose. The monitoring has been completed and the most effective method of controlling acid generation was water cover, followed by limestone, soil cover, phosphate and wood bark. Post-testing on the mineralogy, acid-base accounting, and paste pH of the weathered rock was completed. The relationship between the mineralogy and the quality of the drainage was also investigated.

A case study review on the use of mined out pits as a depository for potentially acid generating materials was started in October. The focus has been to identify suitable pits where in-pit disposal has been used, or is proposed, and to collect relevant information. Good information has been obtained on: technical issues related to in-pit disposal; the diverse practices used and proposed; recently completed successful in-pit disposal programs; and issues/concerns associated with in-pit disposal of waste. What has been found is that the practice of in-pit disposal is more widespread than originally thought.

Table 14: Waste Rock Projects

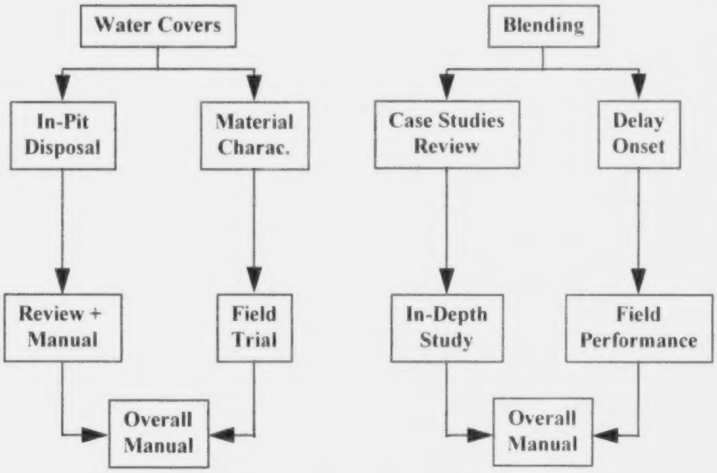
| **Completed Project** | | **Budget($)** |
|---|---|---|
| 2.31.1a | Dry Covers on Waste Rock - Heath Steele | 312k |
| 2.32.1 | Blending and Segregation of Waste Rock - Kutcho Creek | 140k |
| 2.32.2a | Co-disposal of Tailings and Waste Rock in Cells at Les Mines Selbaie | 96k |
| 2.32.3b | Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review | 10k |
| 2.33.1 | ARD Remediation Measures at Four Norwegian Mines | 39k |
| 2.34.1 | Use of Cementitious Covers to Control Acid Generation at Westmin's HW Mine - Shotcrete Field Trial | 130k |
| **Active Projects** | | |
| 2.31.1b | Dry Covers on Waste Rock - Heath Steele | 368k |
| 2.35.2 | Lysimeter Evaluations of Cover Alternatives - Noranda | 279k |
| 2.36.1 | In-Pit Disposal - Case Studies | 50k |
| 2.36.2 | In-pit Underwater Disposal of Oxidized Waste Rock | 166k |
| **Recommended for 1995** | | |
| 2.31.1c | Dry Covers on Waste Rock - Heath Steele | 50k |
| 2.36.3 | Review of Methods for Characterization of Waste Rock Prior to Underwater Disposal | 30k |
| 2.37.1 | Layering - Case Studies | 50k |
| 2.37.2 | Methods for Delaying Onset of AMD - Case Studies | 50k |
| 2.37.3 | Characterization of Test Materials from Samatosum Columns | 35k |
| | **Total** | **1,805k** |
| **Associate Projects** | | |
| | Instrumentation and Evaluation of the Mount Washington Reclamation Project | |
| | Segregation of Waste Rock at the Samatosum Mine | |
| | Placement of Lime Neutralization Sludge on Acid Generating Waste Rock | |

The approach for the in-pit disposal project at Stratmat in New Brunswick, approved in 1994 by the Board, has taken a different approach. The project originally consisted of both a field and laboratory component running concurrently. The scope of the project was reduced to exclude significant field work. The new work plan concentrated more on the laboratory component (data compilation, field sampling of the various materials and a laboratory program). Given the change in scope, MEND is currently reviewing the project's status and the reviews have been favourable.

Considerable uncertainty about the effect of secondary mineral solubility on water quality exists when oxidized waste rock is placed underwater. The committee recommends a review of methods for determining the rate and form of metal release and the resulting total metal loadings. Protocols developed could later be tested at a particular site (e.g. Eskay, Heath Steele -Stratmat) where oxidized waste rock will be placed underwater.

Layering or blending is a close-out option for mines that contain both acid generating and non-acid generating waste rock. The committee recommends that a case study review on the use of blending be carried out. The particulars involved in each of the scenarios would be useful information for operators contemplating a similar disposal technique as part of their waste management philosophy (2.37.1). The committee has identified a need for shorter term, stop-gap prevention methods that could be used to delay the onset of acid generation before permanent disposal measures are taken for closure. A project to investigate the use of temporary methods in a case study format is recommended.

The combination of extensive field monitoring of the actual dumps at Samatosum and the five years of column leachate monitoring provide a rare opportunity to compare laboratory simulations with the resulting performance of layering as a means of ARD prevention. A comprehensive analysis of the residual materials in the columns is recommended and the results will be linked with the field program. This project would give industry a better understanding of the relative effectiveness of blending as an option for close-out.



*Sept '97* *Sept '97*

**Figure 9: Waste Rock**

**Comment:** Figure 9 goes here

## 2.5 Others

This area covers the work that does not logically fit into the other four areas. A general area of research that is identifiable is pre-treatment. This includes chemical, or physical treatment that could prevent acid generation in either the short or long term.

The concept of sulphide separation is being pursued by the committee as a pre-treatment option that could open up several economical disposal options if successful. The separation of sulphides project that reviewed the various conventional mineral processing technologies and their application to the removal of sulphides from four different mill tailings was completed in 1994 (Table 15). The project included a descriptive review as well as bench scale testing of several processing methods. The results proved that the gravity techniques tested were incapable of separating the sulphides sufficiently to remove the acid generating potential of the tailings. This is likely due to the fact that the sulphide portions tend to be concentrated in the finest size fractions of the tailings. The separation technique tested that was successful in removing the acid generating potential of the tailings samples was direct flotation. Before completing large scale field testing of the recommended mineral processing techniques, the Management committee recommended that a case study review on all known sites where sulphide separation was used at one time or another in their operations be completed. The Prevention and Control committee's focus is more on what to do with the desulphurized material (e.g. dry cover) and not the actual method of separation to obtain the material. After further review, the committee recommends that the case study project not be completed.

Existing and new innovative tailings and waste rock disposal methods in terms of their effectiveness in controlling acid production is another area that is being investigated. Two projects on the examination and documentation of different types of tailings disposal methods were continued in 1994. The Disposal Technologies work plan is shown in Figure 10.

Results from the hydrogeological study of the thickened tailings discharge (TTD) method identified four distinct geochemical zones in the cone. The bottom layer has high alkalinity and low dissolved metals. The next layer also has high alkalinity and the water found in the tailings is similar in chemical composition to mill water. The following layer is the jarosite-affected zone. The current practice of co-disposing jarosite with sulphide-rich tailings introduces the jarosite to a neutral-pH and low Eh environment in which it is thermodynamically unstable. It has been found only about 10% of the neutralization capacity would be consumed by the jarosite which is equivalent to about 1% of the carbonates contained in the jarosite affected zone. The only sign of sulphide oxidation is found in the top layer. The products of sulphide oxidation reactions will move through the tailings with the porewater. The hydraulic conductivity in the cone has been reported to be quite low ($10^{-8}$ m/s). The geochemical, hydrogeological, and hydrological studies are confirming that the TTD method has benefits in terms of controlling acidic drainage.

Table 15: Others

| Completed Projects | | Budget($) |
|---|---|---|
| 2.23.2ab | Hydrogeological and Geochemical Analysis of TTD System at Kidd Creek | 149k |
| 2.23.2d | Geochemical Evaluation of the TTD System at Kidd Creek | 250k |
| 2.23.3 | Porous Envelope Surround Disposal Method - Falconbridge | 190k |
| 2.41.1a | Electrochemical Oxidation/Passivation of Sulphides - Small Scale Scoping Studies | 60k |
| 2.42.1 | Development of Synthetic Polymers - Laurentian | 45k |
| 2.44.1 | Microbial Plugging of Mine Tailings to Reduce the Production of AMD | 100k |
| 2.45.1a | Separation of Sulphides from Mill Tailings - Phase I | 75k |
| **Active Projects** | | |
| 2.23.2c | A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the TTD System at Kidd Creek | 78k |
| **Recommended for 1995** | | |
| 2.23.3b | Design Parameters - Pervious envelope and Porous Surround Methods | 25k |
| 2.45.2 | Separation of Sulphides from Mill Tailings - Case Studies* | (50k) |
| | **Total** | **1,022k** |
| **Associate Project** | | |
| | Separation of Sulphides - Field | |

* After review, the Management committee recommended the project not be completed.

**Figure 10: Disposal Technologies**

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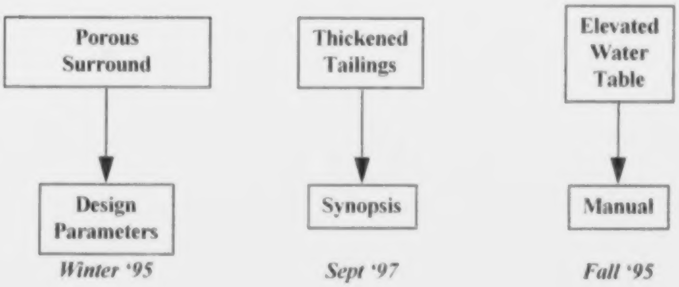

The first set of results for the tracer study on the TTD system had higher-than-predicted velocities. However, subsequent sampling showed that the relative rates were actually slower and in the predicted range. It is believed that advection may have caused the initially higher velocity rates. Core samples, in addition to regular monitoring, will be taken in 1995 to determine if the rates are affected by advection or dilution.

A porous envelope effect may occur in groundwater systems when mine tailings of low permeability are placed within high-permeability soils. If the permeability contrast between the tailings and the natural soil is large, groundwater will flow around the tailings mass rather than through it, and metal leaching will be minimized. Field activities and computer flow modelling conducted over the past three years concluded that conditions for porous envelope containment may be occurring at the Falconbridge Fault Lake tailings site. Water quality sampling did not show any evidence of metal concentrations above background, that suggests minimal leaching of metals from the tailings. Flow modelling supported the porous envelope hypothesis, which corroborates the inference that impact to the regional groundwater by tailings oxidation is insignificant. As a final project for this disposal method, the committee recommends that a review of basic principles and design parameters to obtain the porous effect, for both engineered (Rabbit Lake) and natural (Fault Lake) systems, be completed.

## 3.0 Introduction

The **Treatment committee** met twice in 1994, in Pittsburgh, Pennsylvania during the Third International Conference on the Abatement of Acidic Drainage, and in Val d'Or, Québec. The Val d'Or meeting was combined with a workshop on Chemical Treatment of AMD and field trips to mine waste sites.

There were three active projects at the end of 1994; one project on the recovery of metals from acid mine drainage by ion exchange, a review of passive treatment methods and a project on the use of organic substrates to treat in-situ contaminated sub-surface plumes. A fourth project on the polymerization of sludges was interrupted at an incomplete stage.

The overall program is listed in Table 16 and the balance of the program is shown in Figure 11.

## 3.1 Passive Treatment Methods

The Treatment committee concluded that the use of passive systems to treat acidic seepages is technically feasible but the performance, costs and the applicability of these systems remained uncertain. Several process-limiting factors, such as temperature, flow rates, and rates of addition of bacteria nutrients, had been identified. In order to summarize the results, the committee decided to conduct a summary review of passive treatment systems for the Canadian environment. The contractor's report was received in draft in January 1995 and is being reviewed.

The evaluation, on a laboratory scale, of passive systems for treatment of small seeps was completed in 1994. The systems tested were lime-organic mixtures, anoxic limestone trenches, biotrenches and biosorbents. Because the performance at lower temperature (10°C), showed substantially poorer performance, the Treatment committee did not recommend a field test. The Treatment committee conducted extensive reviews of the reports of the work and concluded that the final report did not meet acceptable standards and the project should be listed as an Associate MEND project. The final report is available as an open file report from the MEND Secretariat.

A project on the use of organic-rich pervious reactor walls indicated that the method has practical promise for treating contaminated groundwater plumes originating from tailings.

## 3.2 Metals Removal From AMD

Two projects were conducted on the removal of metals from acidic drainage before lime neutralization. Bench-scale tests on selective precipitation and ion exchange were completed in late 1993 and late 1994 respectively. The contractor (CANMET) is undertaking additional work recommended by reviewers of the ion exchange report. A second version of the final report on selective precipitation is currently being reviewed in preparation for publication. Based on the recommendations in the laboratory-scale studies, neither ion exchange nor the selective precipitation technique will be tested on a pilot scale. The budget allotment will be switched to sludge and treatment products stabilization.

### 3.3 Lime Treatment and Sludge Stabilization

The major emphasis for the balance of the MEND Treatment program will include; the review of lime treatment technology; production of a manual on lime treatment; and the determination of methods to stabilize treatment products. The project to review the state-of-the-art for lime treatment and sludge stabilization was completed. The contractor published the results in workshop format at the Val d'Or and Vancouver workshops. At least one additional workshop will be held on this subject in 1995.

The report on lime treatment recommended that investigations are needed on the stabilization of lime treatment sludges. This recommendation was reinforced by industrial and government participants at the chemical treatment workshops. In addition, several industrial uses of lime treatment sludges should be investigated. The Treatment committee agrees with these recommendations and a project is proposed for 1995. This project will complete the mandate of the Treatment committee, and it is expected that this work will be finished in late 1996.

A project at Laurentian University to examine the use of polymer-modified sludges as a capping material for waste rock or tailings had to be abandoned because of the death of the principal investigator. The university is preparing a summary report on the work.

A small project on the use of specific bacteria to stabilize pyrite surfaces was forwarded from the New Ideas Task Force for consideration, and is recommended for the 1995 program.

### 3.4 Committee Mandate and Operation

The Treatment committee is nearing completion of its mandate as defined in the 1992 Revised Research Plan. The remaining major issue is that of treatment products. To ensure that this task is completed in a suitable way, the committee will remain as a separate committee until at least the end of 1996, and possibly after the 4th International Conference in June 1997.

**Table 16: Treatment**

| **Completed** | | **Budget($)** |
|---|---|---|
| 3.11.1a-d | Treatment of Acidic Seeps Employing Wetland Ecology and Microbiology - 1988-93 | 759k |
| 3.12.1a | Assessment of Existing Natural Wetlands Affected by Low pH, Metal Contaminated Seepages - 1990 | 40k |
| 3.12.2 | Evaluation of Wetlands at the Panel Dam "A" Site | 45k |
| 3.13.1a | Treatment of Small Seeps | (90k)* |
| 3.21.1a | Metals Recovery from Acid Mine Drainage | 25k |
| 3.21.2a | Metals Removal from Acid Mine Drainage - Chemical | 90k |
| 3.22.1 | Survey of Acid Mine Drainage Characteristics | 15k |
| 3.32.1 | Lime Treatment - Review and Sludge Stabilization | 60k |
| **Active** | | |
| 3.14.1 | Review of Passive Systems for Treatment of AMD | 60k |
| 3.21.1b | Metals Removal from Acid Mine Drainage - Ion Exchange | 64k |
| 3.31 | Use of Lime Sludges for Capping | 30k |
| 3.41.1a | In Situ Treatment of AMD | 41k |
| **Recommendations for 1994** | | |
| 3.41.2 | Biological Fixation of Sulphides | 20k |
| 3.42.2 | Lime Sludge Stabilization, Disposal and Use | 105k |
| | **Total** | **1,354k** |

**Associate Projects**

Field Evaluation of Acid Mine Water Treatment Using
Constructed Wetlands at the Halifax Airport
Constructed Wetland at Noranda Bell Mine
Treatment of Acidic Seepage Using Chinese Alders
Use of Fluidized Bed Combustion Ash to Treat AMD (Nova Scotia)
Use of Lime Sludge to Cap Waste Rock (New Brunswick)
* Treatment of Small Seeps

* Removed from full MEND Project Status

Figure 11: Treatment 1995-1997

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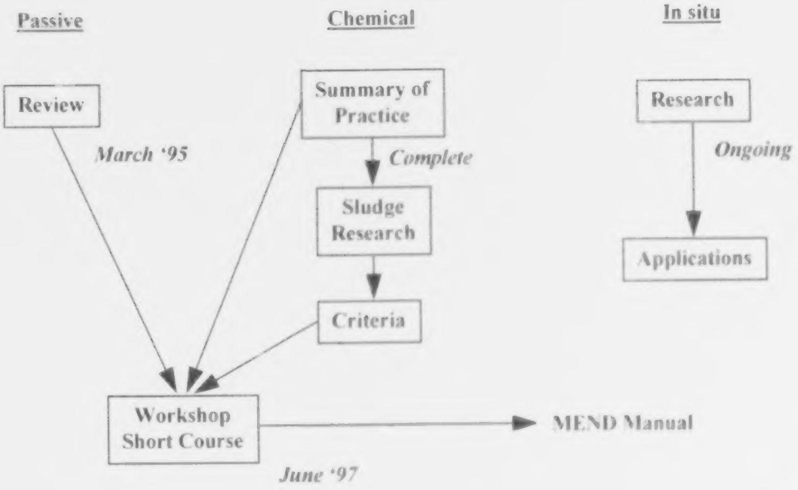


## 4.0 Introduction

Several **Monitoring** projects were completed last year, including: the Waste Rock Sampling Manual; two projects related to remote monitoring and geophysical techniques; and two projects investigating new methods for the *in-situ* analysis of mine tailings or the *in-situ* detection of acidic contamination entering receiving waters. The two latter projects employed new technologies only recently developed. A project aimed at revising the B.C. AMD Taskforce technical guide was also completed. However, the report was not of acceptable quality and a revised scope will be prepared in 1995.

Also completed was the processing of the first standard (non ore-grade) material for Net Neutralization Potential (NNP). Further standard development work is now under the direction of Prediction.

## 4.1 1995 Program

The project on the extension of geophysical techniques to the detection and monitoring of acidic drainage has been terminated after consultation with the industry. It is felt by experts in the field that further research in this area by MEND would not yield value-added results. The investigation of alternative geophysical techniques should be addressed only after the theoretical significance of the results are well understood.

Only two projects are planned for 1995. A new, facile method for measuring indirectly the oxidation potential of both waste rock and tailings is proposed. A Monitoring Manual is also recommended for development in the coming year. This project will develop a concise manual to assist industry and government agencies across Canada to achieve consistency in implementing monitoring programs, developing comparative data bases, and to assist in the use of appropriate scientific techniques.

The formation of the new Aquatic Effects Technology Evaluation (AETE) program resulted in the transfer of all future biological related projects from Monitoring to this program. AETE is a program like MEND, a cooperative program of the Canadian mining industry and several government departments. CANMET provides the AETE Secretariat.

As for the operations of the Monitoring Committee, a joint Monitoring-Prediction meeting will be held June 1, 1995 following the Sudbury '95 conference. This meeting will be pivotal in determining the future direction of the Monitoring

Committee. A motion to amalgamate the Prediction and Monitoring committees will be tabled.

The final components of the Monitoring program is summarized in Figure 12, and all of the projects are listed in Table 17.

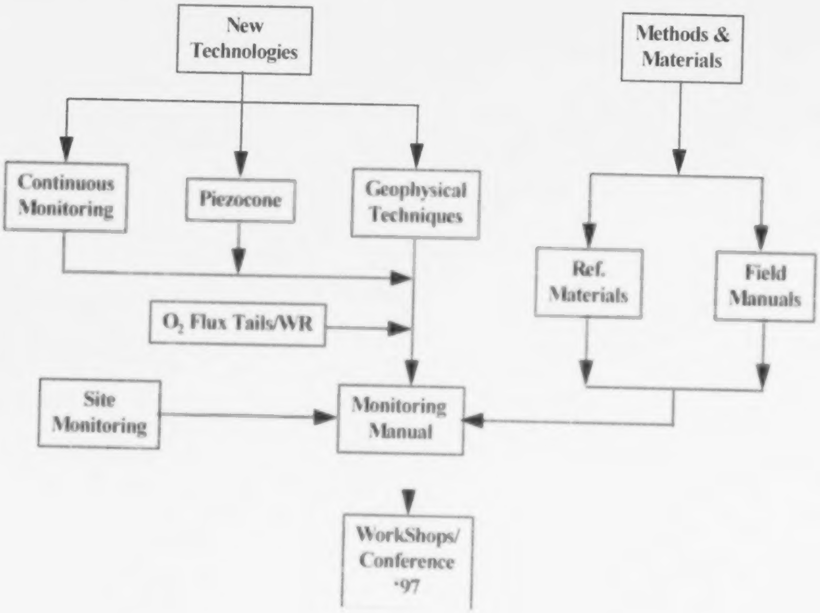
**Table 17: Monitoring**

| **Complete** | | **Budget($)** |
|---|---|---|
| 4.1.1 | Field Methods Manual - Tailings | 29k |
| 4.2.1 | Decommissioning Criteria | 15k |
| 4.3.1 | Standard Reference Materials - Tailings | 50k |
| 4.3.2 | Standard Material - Net Neutralization Potential | 28k |
| 4.5.1 | Field Methods Manual - Waste Rock | 80k |
| 4.5.2 | Field Sampling QA/QC | 10k |
| 4.5.3 | ARD Technical Guide Revision - Monitoring Section | 50k |
| 4.6.1 | Assessment of Geophysical Monitoring Methods | 118k |
| 4.6.2 | Continuous Monitoring of AMD - Literature Review | 50k |
| 4.6.3 | Remote Monitoring Techniques - Review | 60k |
| 4.6.4 | Piezocone Field Test | 27k |
| 4.7.1 | Optimum Sampling Frequency | 27k |
| 4.7.2 | Biological Monitoring of AMD | 21k |
| 4.7.3 | Aquatic Invertebrate Monitoring | 136k |
| 4.7.4 | AMD Sediment Monitoring | 7k |
| 4.7.5 | Ion Speciation | 35k |
| 4.7.6 | Paleolimnology Techniques | 17k |
| 4.8.1 | Monitoring of the Flooded Solbec Pit | 139k |
| 4.8.2 | Sediment Sampling Probe - Field Application | 51k |
| **Recommended** | | |
| 4.5.4 | Environmental Monitoring Handbook for Acid Mine Drainage | 80k |
| 4.6.5a | Demonstration of a Field Method to Determine the Oxygen Flux Across the Surface of Tailings | 11k |
| 4.6.5b | Demonstration of a Field Method to Determine the Oxygen Uptake of Waste Rock | 15k |
| **Removed** | | |
| 4.6.1b | Geophysical Monitoring: Further Application & Development | (100k) |
| | **Total** | **1,056k** |
| **Associate** | | |
| | Remote Sensing to Monitor Uranium Tailings Sites - AECB | |

The overall direction, both past and present, of the Monitoring Committee is presented as a flow chart on the following page. All projects are inter-related and ultimately tie into the Monitoring Manual.

**Figure 12: Monitoring Program**

**Comment:** Figure 12 goes in here



## 5.0 Introduction

**Technology Transfer** is an increasingly important activity for the MEND program. During 1994, the committee expanded its activities, to get the results of the program transferred to the users. The full program is listed in Table 18 and the components remaining to complete are shown in Figure 13.

## 5.1 Workshops/Conferences

Workshops were presented in Val d'Or, and Vancouver on Chemical Treatment of Acid Mine Drainage, and in Sudbury and Vancouver on Economic Evaluation of Acid Mine Drainage Technologies. These workshops were very successful according to feedback received from the participants. Additional workshops are planned during 1995 on various topics. It is planned that workshops will continue to be delivered up to 1997 when short courses are planned at the 4th Conference on the Abatement of Acid Rock Drainage in Vancouver in 1997.

MEND also participated, as a co-sponsor with the United States Bureau of Mines, in the organization and staging of the Third International Conference on Abatement of Acidic Drainage held in Pittsburgh, in April, 1994. This conference, which was co-billed with the International Land Reclamation Conference, was attended by over 1,200 delegates and was a technical and financial success. Forty-three Canadian papers and posters on acid mine drainage were presented, the most of which reported the results of MEND work.

The Fourth International Conference on Acid Rock Drainage is proposed for June 2 to 4, 1997 in Vancouver, British Columbia. An organizing committee has been formed and is co-chaired by Mike Filion of Teck Corporation and George Poling of the University of British Columbia. The theme of this conference will be "**Application of Technology**" and short courses will be given on acid drainage prevention and remediation by experts from MEND and from around the world.

Ontario (MEND Ontario) and Québec (Comité DMA-Québec) are planning workshops in the fall of 1995. Several MEND papers will be presented at the "Sudbury '95" conference in May, 1995.

## 5.2 Communications/Publications

In addition to the publication of MEND reports, the MEND Newsletter is distributed to over 650 individuals and organizations to keep them informed on the recent results of MEND projects. Two issues of the Newsletter were published in 1994, and publication will continue in the remaining three years of the program.

Four communications vehicles had been identified in 1993 to inform key audiences about the issue of acidic drainage and the new affordable technologies being developed to solve the problem. The vehicles were the CIMM Distinguished Lectures Series, a print brochure to convey basic information about AMD and MEND, a series of television programs on the Mining Industry, and a video on AMD and MEND.

Mr. Louis Sirois was nominated as CIMM distinguished lecturer, and Mr. Sirois has presented to 6 local CIMM branches. His presentations were very well received. Additional presentations will be done in the first half of 1995.

Considerable effort was expended by many volunteers and the MEND Secretariat in providing material and editing of a video on MEND and acidic drainage. A 20-minute version for "technical" audiences has been produced along with a 12-minute version for the general public. Both versions, which are available in both English and French, will be distributed in May 1995.

At year end, there was a considerable backlog of MEND reports requiring publication. To help reduce this backlog and publication costs, steps have been taken to make reports available in electronic format - computer discs, CD-ROM and via INTERNET.

At year end a scope of work and a request for proposal were prepared for the production of a "MEND Manual" that will be available at the end of the program. This manual will be prepared in 2 phases, with phase I ending in March 1997, and Phase II ending in June 1998. Phase II will include all of the results of the program and will be in English and French. The Manual will summarize the results of MEND and will include the results of important technology developed outside of MEND.

## 5.3 Databases

In 1994, the Technology Transfer committee again reviewed the functioning and usefulness of the Laurentian University Database. The Database (Abandoned Mines, Acid Mine Drainage and Land Reclamation) contains over 10,000 abstracted references and is available on-line through INTERNET or through the purchase of diskettes. The committee was disappointed with the rate that recent information and MEND reports are being added to the database, and with the lack of quality assurance of information in material being added. The committee has asked Laurentian for a proposal on improving the usefulness of the database concerning acidic drainage.

Two databases have been developed at the University of British Columbia through the Prediction Committee. They focus specifically on the prediction of acid mine drainage and on data management. The DBARD (Database for Acid Rock Drainage) project (1.12.1) will continue adding information until 1996, while the Waste Rock Dump Monitoring Database project (1.41.2) was completed in March 1994.

### 5.4 Economic Evaluation

The MEND Secretariat completed a Canada wide survey of acid-generating mine waste sites and estimated the liability associated with these sites to be between $2 and $5 billion. The higher cost estimate is attributable to the placement of dry multi-zone earth covers and a short time of water treatment after cover completion. (The report of this survey is available from the Secretariat).

A project was completed on the determination of the base cost of prevention, control, and treatment of acid mine drainage with existing technology, and the development of a protocol for economic evaluation of existing and emerging technologies. Workshops were given on this project in Sudbury and Vancouver.

### 5.5 Intellectual Property

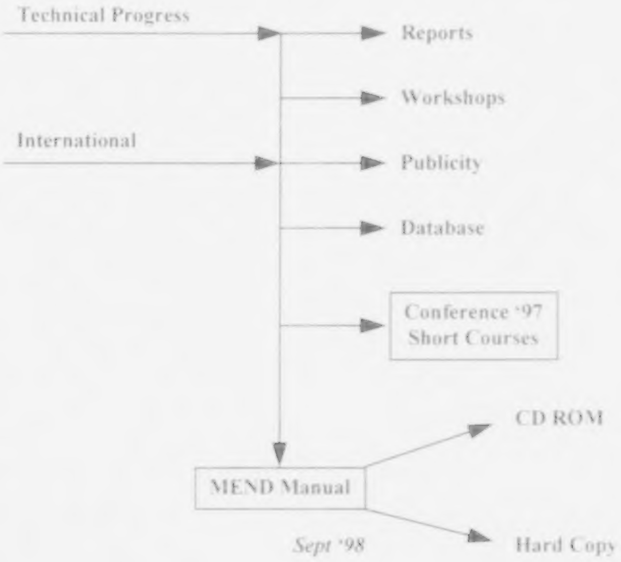
There were no significant Intellectual Property issues for MEND in 1994.

Table 18: Technology Transfer

| **Complete** | | **Budget($)** |
|---|---|---|
| 5.1.1a-c | Provincial Workshops | 29k |
| 5.3.1 | Laurentian Database | 35k |
| 5.3.2 | Expand Databases at Laurentian & UBC | 12k |
| 5.4.1 | Acid Rock Drainage Technical Guide - version française | 24k |
| 5.5.1 | Preliminary MEND Research Plan | 25k |
| 5.6.1 | Second International Conference on the Abatement of Acidic Drainage | 127k |
| 5.6.2 | Third International Conference on the Abatement of Acidic Drainage | 15k |
| 5.8.1 | Economic Evaluation of MEND-developed Technology | 40k |
| **Active** | | |
| 5.2.1a-c | Communications Plan - CIMM Lectures, Brochure, TV Series | 5k |
| 5.2.1d | Communications Plan - Video on AMD/MEND | 150k |
| 5.4.2 | AMD/ARD Handbook - Phase I | 150k |
| 5.7.1 | MEND Newsletter | 3k |
| **Recommended for 1995** | | |
| 5.1.2 | Workshops | |
| 5.6.3 | Fourth International Conference on Acid Rock Drainage | 80k |
| 5.7.2 | Publications - CD ROM | 60k |
| | **Total** | **755k** |
| **Other Initiatives** | | |
| | Report Distribution by CANMET | |
| | Seminars, Conference Presentations, International Information Exchange | |

Figure 13: Technology Transfer 1995-1998

Comment: Figure 13 goes here



### 6.0 Introduction

International interest in the MEND program continues to be strong. This interest is shown in three ways: frequent requests for technical information on MEND results; questions about MEND as an industry-government cooperative effort; and the results of field tests.

**International Liaison** is not formalized into a committee, but is instead an informal network of contacts through the MEND Secretariat and technical committees.

### 6.1 1994 Activities

The principle activity during 1994 was the exchange of written information and ideas with international mining companies and organizations. The MEND Secretariat hosted several international visitors, and the network of international contacts continued to be expanded.

An important step in extending international information exchange on the subject of acidic drainage was participation in the International Land Reclamation and the Third International Conference on the Abatement of Acidic Drainage in Pittsburgh, in April 1994. This was the largest mine reclamation conference ever held; over 1,200 people from around the world attended. At this conference, 43 papers and posters were presented by Canadian authors, the most of which were reporting results of MEND projects.

Also at the Pittsburgh Conference, the MEND Secretariat hosted a half-day workshop entitled "International Acid Mine Drainage Research Programs". MEND has prepared a summary report of the proceedings of this workshop (see MEND Reports Available in Appendix F).

Cooperation continues to be strong with agencies and individual scientists in many countries, particularly those in the United States and Europe. Twenty individuals from the United States, principally from the US Bureau of Mines, participate in MEND technical committees as full or associate members. Important technical developments in the United States in chemical predictive techniques, modelling, dry covers, and passive water treatment systems are being closely monitored by MEND.

MEND provided comments on a 2-year Swedish "Mine Waste Research Plan" on acid-generating mine wastes, and will review reports when the work is completed. Sites in Sweden and Norway
that have been closed for some time are providing valuable monitoring information on remedial techniques for acid-generating tailings and waste rock.

Organizations such as ANSTO in Australia have contributed to the understanding of the fundamental principles of waste rock pile dynamics, and have contributed to MEND on the Heath Steele project (1.22.1), and are actively working with Canadian mining companies and researchers.

Information exchange is continuing with the researchers in Ireland, England and Greece on a European Union-funded project on remediating acid mine drainage sites.

### 6.2 1995 Program

For 1995, international liaison will continue to formalize contacts for information exchange in several countries. Interest has been expressed in MEND by agencies and mining companies in Brazil, Argentina, Indonesia and Australia. The MEND Newsletter, which is currently mailed to over 300 international contacts will continue to be an important method of contact. International electronic data linkages, such as INTERNET, will be used for information exchange including abstracts of MEND reports. International mining companies will be the primary focus of the information exchange, particularly with respect to the acid drainage problems encountered in various climates and the results of remedial actions that have been put in place.

A visit is planned to remediated sites in northern Europe by members of the MEND Secretariat and MEND committees in the summer of 1995.

International Liaison will cease to be listed as a separate committee; international initiatives will continue under the Technology Transfer committee.

### 7.0 Introduction

A **New Ideas Task Force** was approved by the MEND Board in August of 1992. The Task Force was set up to solicit and develop new ideas and innovation that could provide technology to significantly reduce the cost of preventing, controlling and treating acidic drainage. To date there have been two rounds of proposal solicitation.

### 7.1 Proposal Solicitation - Rounds 1 and 2

A simple and concise proposal format was developed and distributed Canada-wide in late 1992. Universities were targeted in the first Round. MEND members were canvassed for up-front seed funding. Ninety proposals were received and evaluated and eleven were accepted for funding. Using the results of the first round of solicitation as a guide, the Task Force initiated a second solicitation in late 1993. By the end of the year, 58 proposals had been received and an initial evaluation showed that 7 proposals had merit for closer consideration by the Task Force. Also, several proposals appeared to be focussed on areas of work that were the responsibility of technical committees.

In January, 1994, the New Ideas Task Force evaluated the results and made recommendations for the remaining years, 1994 to 1997, of the MEND program. The Task Force suggested that MEND:

- Discontinue annual solicitation, screening and contract management;
- Continue to screen and review unsolicited "new ideas" proposals;
- Recommend where appropriate brainstorming, questionnaires, interviews;

and

- Implement new ideas projects by technical committees with "champions."

The Task Force was disbanded in April 1994, and the chairman, Mr. K. Wheeland was contracted by CANMET to ensure the completion and publication of work initiated in both rounds of proposal solicitation.

Of the 18 projects sponsored, 15 are completed and it is expected that the 3 remaining will be completed in mid-1995. Three of the projects show promise for significant breakthrough in reducing liabilities caused by acidic drainage: Permafrost, Modified Clay and Polyurethane Covers. All three have "niche" potential. Other projects with "long shot" potential are:

- Low Cost Wax Cover;

- Commingled Tailings and Waste Rock; and
- Limestone Precipitate Layer.

The Modified Clay and Selective Ion Exchanger projects were continued to a second "proof-of-concept" stage. The Critique of Japanese AMD Research summarizes some interesting remedial and treatment technology at an old pyrite mine in Japan. The technology is being tested on a metal drainage "cocktail" using lime as a pH modifier.

**Table 19: New Ideas Projects - Rounds 1 and 2**

| New Ideas # | Title | Proponent | Budget($) |
|---|---|---|---|
| 01* | Status of U.S. Research | Tarassoff | 9k |
| 02* | Permafrost to Prevent AMD | Geocon | 9k |
| 03* | Low Cost Wax Cover | CANMET | 10k |
| 04, 21* | Chemically Modified Clay | Alberta Research Council | 30k |
| 05 | Ferric Phosphate Coating | Laval | 10k |
| 06* | Japanese Technology | Laurentian University | 10k |
| 07* | Artificial Hardpan | CANMET | 10k |
| 08 | Passivation of Sulphides | Technical University N.S. | 5k |
| 09. 22 | Selective Ion Exchange Resin | McGill University | 20k |
| 10 | Chelating Ribbons | University of Manitoba | 10k |
| 11 | Commingled Waste Disposal | University of B.C. | 10k |
| 12 | Chelating/Membrane Filtration | Zenon | 10k |
| 13, 20* | Polyurethane Covers | Queen's University | 15k |
| 14* | Foam Flotation Lit. Rev. | Noranda | 3k |
| 15 | Limestone Precipitate Layer | ADI Nolan Davis | 10k |
| 16* | Ion Flotation | Laurentian University | 10k |
| 17 | Sulphide Passivation | Laurentian University | 10k |
| 18* | Polymer Gel Cover | Universite Laval | 10k |
|  | Administration costs | Ken Wheeland | 49k |
|  |  | **Total** | **250k** |

Eight of the new ideas reports(*) are available as MEND reports; the others as Open File Reports from the MEND Secretariat.

# APPENDIX A
## MEND Board of Directors Committee Members

Mr. Donald Barnett
Assistant Deputy Minister
N.B. Natural Resources and Energy

Mr. Henry Brehaut
Senior Vice-President
Placer Dome Inc.

Mr. H.A. (Tony) Clarke
Assistant Deputy Minister
Environment Canada Conservation and Protection

Dr. W.R.(Dick) Cowan, Director
Ontario Ministry of Northern Development & Mines

Dr. Marc-Denis Everell
Assistant Deputy Minister
Mineral & Energy Technology Sector
Natural Resources Canada

Mr. Charlie Ferguson
Vice-President, Environment Health & Safety
INCO Limited

Mr. Michael Fine
Deputy Minister
Manitoba Energy and Mines

Mr. Wayne Fraser
Director, Safety and Environment
Hudson Bay Mining & Smelting Co.

M. Louis P. Gignac, President
Cambior

Dr. Irwin Itzkovitch, Director General
Mineral Technology Branch
Natural Resources Canada

Mr. Walter J. Kuit
Manager, Environmental Affairs
Cominco Ltd.

M. Jacques Lebuis
Sous-ministre associé aux mines
Ministère des Ressources naturelles du Québec

Mr. Mike P. Lipkewich
Senior Vice-President, Mining
Teck Corporation

Mr. Jacques McMullen
Manager, Metallurgy
Barrick Gold Corporation

Mr. Bruce McRae
Assistant Deputy Minister
B.C. Ministry of Energy, Mines & Petroleum Resources

Dr. C. George Miller
President
Mining Association of Canada

Mr. John S. Rayner
Assistant Deputy Minister
Department of Indian and Northern Affairs

Mr. Patrick Reid, President
Mining Association of Ontario

Mr. Larry Seeley
Vice-President, Environmental Services
Falconbridge Limited

Mr. John White
Managing Director, Chile
Falconbridge Limited
Chairman, MEND Board of Directors

**Resource Persons:**

Mr. D.G. FeasbyManager, MEND Secretariat, CANMET
Mr. M.P. Filion Vice-President, Environment, Teck Corporation
Mr. Hennie Veldhuizen Vice-President, Environment, Noranda Mining and Exploration Inc.

## MEND Management Committee Members

Mr. Art Ball, Director of Mines
Manitoba Energy & Mines

Dr. Martin Barnett
Senior Advisor
Department of Indian and Northern Affairs Canada

Mr. Victor Buxton
Director, Industrial Sectors Branch
Environment Canada

Mr. Andy Cormier
President and General Manager
NB Coal Limited

Dr. W.R.(Dick) Cowan, Director
Ontario Ministry of Northern Development & Mines

Dr. John Errington, Manager, Reclamation
B.C. Ministry of Energy, Mines & Petroleum Resources
Mr. Grant Feasby
Manager, MEND Secretariat
CANMET

Mr. Mike Filion
Vice-President, Environment
Teck Corporation

Mr. Wayne Fraser
Director, Safety and Environment
Hudson Bay Mining & Smelting Co.

M. Claude Gignac, Ingénieur
Ministère de l'Environnement et de la Faune du Québec

Mr. Ron Hore, Regional Director
Ontario Ministry of Environment and Energy

Mr. Tom Hynes
Program Principal, Acid Mine Drainage
CANMET

Dr. Irwin Itzkovitch, Director General
Mineral Technology Branch
Natural Resources Canada

Mr. Dan Khan, Mining Engineer
N.S. Department of Natural Resources

Mr. Walter J. Kuit
Manager, Environmental Affairs
Cominco Ltd.

Dr. Ed Kustan
Manager, Environmental Assurance
INCO Limited

Dr. Joseph Lazarovich
Director of Mineral Resources
Dept. of Indian and Northern Affairs Canada

M. Gilles Mahoney
Direction de l'industrie minérale
Ministère des Ressources naturelles du Québec

Mr. Sam McEwan, Director of Mineral Development
N.B. Department of Natural Resources & Energy

Mr. Ferd Morrissey, Manager, Engineering Analysis
Newfoundland Department of Mines and Energy

Mr. William A. Napier
Director, Environmental Affairs
Homestake Canada

Mr. Ron Nicholson, Vice-President, Environment
Cape Breton Development Corporation

Dr. George Poling
Professor of Mineral Process Engineering
University of British Columbia

Mr. Jim Robertson
Manager, Environmental Engineering
Placer Dome Inc.

Mr. Michael Sudbury
Director, Environmental Services
Falconbridge Limited

Mr. Leonard Surges, Director, Environment
Brunswick Mining and Smelting Corporation Ltd

Mr. Al Vivyurka
Senior Environmental Engineer
Rio Algom Limited

Mr. Ken Wheeland
Environmental Facilitator
Ken Wheeland Eng.

Mr. Ken B. Yuen
Director Oceanography & Contaminants Branch
Fisheries and Oceans Canada

Mr. Bernie Zgola
Head, Decommissioning & Mine Impacts Section
Atomic Energy Control Board

## Resource Persons:

Mr. G. Tremblay, Coordinator, MEND Secretariat, CANMET
Mr. C. Weatherell, Coordinator, MEND Secretariat, CANMET

# APPENDIX B
## Projects Completed Before 1994

| Number | Titles |
|---|---|
| 1.11.1 | AMD from Waste Rock - Literature Review |
| 1.12.1a | Compile AMD Prediction Data - DBARD |
| 1.14.1 | Field Evaluation Rock Hydrochemistry - Mine Doyon Phase I |
| 1.15.1 | AMD from Open Pits - Equity Silver |
| 1.16.1a | Evaluation of Predictive Techniques |
| 1.16.1b | Manual of Chemical Evaluation Procedures |
| 1.16.1c | Development of Static Evaluation Procedures |
| 1.17.1 | Hydrogeochemical Investigation - Waite Amulet Reactive Tailings |
| 1.19.1 | Kinetic Test for Cinola Gold Project |
| 1.21.1a | Evaluate RATAP.BMT2 Capabilities |
| 1.21.1b | Workshops of Modelling Techniques - Tailings |
| 1.21.1c | Modelling of Reactive Tailings - Prepare RATAP Users Manual |
| 1.24.1 | Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps |
| 1.25.1 | Development of a Soil Atmosphere Flux Model for Design of Sulphide Tailings Cover Systems - Phase I |
| 1.26.1 | Development of a Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock - Phase I |
| 1.31.1 | Geochemical Study of Weathering Employing Secondary Ion Mass Spectrometry |
| 1.32.1 | Prediction and Prevention of Acid Rock Drainage - A Geological and Mineralogical Approach |
| 1.41.1 | International Waste Rock Modelling Workshop |
| 2.11.1a-c | Evaluation of Existing Underwater Disposal Sites |
| 2.11.1d | Peer Review on the Subaqueous Disposal of Tailings |
| 2.11.2a | Literature Review Report: Possible Means of Evaluating the Biological Effects of Subaqueous Disposal of Mine Tailings |
| 2.14.1 | Establish Vegetative Wetlands over Tailings |
| 2.21.1 | Engineered Dry Covers for Tailings |
| 2.21.2 | Engineered Dry Covers for Tailings - Noranda |
| 2.22.1 | Assessment of Hardpan |
| 2.23.1 | Documentation of Disposal Methods for Tailings and Waste Rock (Draft Acid Rock Drainage Technical Guide) |
| 2.23.2ab | Hydrogeological and Geochemical Analysis of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines |

| Number | Titles: |
|---|---|
| 2.24.1 | Vegetation Manual "Manual of Methods used in the Revegetation of Reactive Sulphide Tailings Basins" |
| 2.31.1a | Dry Covers on Waste Rock - Heath Steele |
| 2.32.1 | Blending and Segregation of Waste Rock - Kutcho Creek |
| 2.32.2a | Co-Disposal of Tailings and Waste Rock in Cells - Les Mines Selbaie |
| 2.33.1 | ARD Remediation Measures at Four Norwegian Mines |
| 2.41.1a | Electrochemical Oxidation/Passivation of Sulphides |
| 2.44.1 | Microbial Plugging of Mine Tailings to Reduce the Production of AMD |
| 3.11.1a-c | Treatment of Acidic Seepages Employing Wetland Ecology and Microbiology - Phases A,B and C |
| 3.11.1d | Treatment of Acidic Seeps Employing Wetland Microbiology (ARUM) |
| 3.12.1 | Assessment of Natural Wetlands Affected by Low pH / Metal Contaminated Seeps |
| 3.12.2 | Evaluation of Wetlands at Panel "A" Site |
| 3.21.1a | Metals Recovery from Acid Mine Drainage - Phase A |
| 4.1.1 | Field Methods Manual - Tailings |
| 4.2.1 | Decommissioning Criteria |
| 4.3.1 | Standard Reference Materials - Tailings |
| 4.5.2 | Field Sampling Quality Assurance/Quality Control (QA/QC) |
| 4.6.2 | Continuous Monitoring of AMD - Literature Review |
| 4.7.1 | Optimum Sampling Frequency |
| 4.7.2 | Biological Monitoring of Acid Mine Drainage |
| 4.7.3 | Aquatic Invertebrate Monitoring |
| 4.7.4 | Acid Mine Drainage Sediment Monitoring |
| 4.7.5 | Ion Speciation |
| 4.7.6 | Paleolimnology Techniques |
| 4.8.1 | Monitoring of the Flooded Solbec Pit |
| 5.1.1a-c | Provincial Workshops |
| 5.3.1,2 | Laurentian Database |
| 5.4.1 | Acid Rock Drainage Technical Guide - version française |
| 5.5.1 | Preliminary MEND Research Plan |
| 5.6.1 | Second International Conference on the Abatement of Acidic Drainage |

*PREDICTION*

**Project 1.11.1: AMD from Waste Rock - Literature Review**
**Expenditures:$50,000**

A critical review of existing information on acid-generating waste rock has been carried out as a basis for further work. Relevant information on theory, experiments, modelling and field studies were assessed for their validity and applicability. The impacts of various construction techniques on phase migration, solid, liquid, and gas, were assessed. Water movement and the migration of solids within rock piles were found to be dependant on hydraulic conductivity, hydraulic gradients, degree of saturation, and laminar versus turbulent flow. The migration of solids was defined in terms of internal migration and geotechnical failures, and gas transport, primarily through gaseous advection. The primary reactions were identified as: acid generation, which may be driven by abiotic and biological factors; acid neutralization; and metal leaching. Acid neutralization is a highly complex series of aqueous and mineral reactions. Speciation analyses were identified as useful but under-utilized. The parameters associated with the rate and extent of metal leaching were identified and discussed. This review is available as a MEND report.

**Project 1.12.1a: Compile AMD Prediction Data - DBARD**
**Expenditures:$44,600**

The objective of this project was to develop an acid mine drainage database of prediction test results by developing an accessible user-friendly database program, and adding available prediction data for mine projects in B.C. initiated subsequent to 1980. The data can then be analyzed for common trends and important differences, and recommendations made for improved approaches to pre-mine prediction.

A computer database has been developed through Morwijk Enterprises using dBase III plus. A comprehensive user's manual for Version 2.0 of the database has also been completed and both the manual and database are available through the Chair for Mining and the Environment at the University of British Columbia. DBARD contains a significant quantity of prediction and other mine component characterization data for 119 mines in British Columbia. The database includes information on mines, mine component analyses, metal leach tests, static tests, and kinetic tests. Data are available on over 3,000 samples, including 3062 static test results, 1061 kinetic test cycle results, and metal analyses for 756 samples.

### *PREDICTION*

The information input to date still only represents a small percentage of the huge quantity of ARD prediction data that have been generated over the past few years. Further data entry is therefore recommended both within and outside British Columbia. It is also recommended that the database be made more generally available. A program to maintain and further develop the database is being proposed for 1994 (1.12.1b).

## *PREDICTION*

### Project 1.14.1: Field Evaluation Rock Hydrochemistry - Mine Doyon Phase I

**Expenditures:$362,000**

Initial dump characterization of the 21 million tonne Mine Doyon waste rock pile in Québec was carried out through review and evaluation of all available site documentation. In-depth characterization (physical, chemical and hydrological) was done using: boreholes penetrating the entire thickness of the rock pile and into the bedrock; boreholes along the perimeter to sample groundwater; exploration pits to observe alteration phenomenon; and weir stations in the drainage ditches to measure water flow. An inventory and assessment was made of all granular material available for use as a (composite) dry cover, but although suitable materials were identified, differential compaction in the dump due to weathering does not favour the installation of a natural cover. Based on heat and mass balances it is estimated that 7000 tonnes of pyrite ($<1\%$ of total) oxidize per year and that the amount of pyrite in the dump has not been significantly depleted. Temperature profiles indicate that oxidation is in a steady state and may be maintained for at least another 100 years. More detailed studies related to prediction are ongoing (1.14.2). A comparison of mineralogical content with leachate chemistry will help understand reactions of leachate formation and transformation.

### Project 1.15.1: AMD from Open Pits - Equity Silver

**Expenditures:$53,000**

The overall objectives were to assess relative contributions of AMD sources in open pits and to develop an applicable computer model of such a system. All relevant information on water movement and chemistry on and within mine walls was reviewed. Acidic conditions appear to be at least partially due to unsaturated fractures. The rates of acid generation and neutralization on exposed pit walls of the Main Zone Pit at Equity Silver in British Columbia were determined using field studies and existing mine data. The importance of detailed baseline studies of groundwater prior to mining was emphasized. Metal leaching is strongly dependant on aqueous speciation and mineral solubility. A computer code, MINEWALL, was created to emulate open pits during operation and decommissioning and applied using site-specific information. In the case of Equity Silver, it was predicted that the flooded pit would return to neutral after the initial acid flush. MINEWALL has undergone preliminary verification but was not finalized for general use. Further development is ongoing (1.15.2).

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### Project 1.16.1a: Evaluation of Predictive Techniques

**Expenditures:$63,000**

To predict the generation of acid mine drainage from mine wastes, there are several methods available of varying complexity. These methods have been evaluated to assess their reliability when applied to the field and to recommend those with the most promise for determining the potential for generating acid drainage. The following documented chemical prediction static and kinetic procedures were evaluated and compared: B.C. Research Initial test; Acid Base Accounting; Sulphur Ratio test; $H_2O_2$ for Pyrite Estimation; B.C. Research Confirmation test; Humidity Cell test; Shake Flask Weathering test; Soxhlet Extraction test; and Manometric Carbonate Pressure Analysis. In addition, three more recently developed tests were evaluated: Net Acid Production test; Modified Biological Confirmation test; and Modified Acid Base Accounting. Evaluations were carried out by performing each procedure on eight tailings samples and four waste rock samples from Canadian mines. The advantages and limitations of each method are discussed. The documentation of the above procedures in a detailed user's manual format was recommended (1.16.1b).

### Project 1.16.1b: Manual of Chemical Evaluation Procedures

**Expenditures:$23,000**

A user's guide has been produced for the application of chemical evaluation procedures (identified in 1.16.1a) for the prediction of acid generation from mining wastes and related materials. The manual provides background information on acid generation from mine wastes and applicable references. An integrated approach to acid mine drainage prediction strategy is also outlined. Guidelines to the application of the individual prediction tests, details of procedures and associated considerations are addressed. The balance of the manual is devoted to the detailed descriptions of recommended and alternate chemical predictive procedures. Six static (short term) methods and five kinetic (longer term) methods are described. For each method, the applicability, objectives, advantages and disadvantages are discussed. The test principles, equipment and reagent requirements, test procedure interpretation and manner of result reporting are outlined in detail. To date there is no single chemical predictive method that is applicable to all waste materials and/or situations. Further development is seen as essential (1.16.1c).

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**Project 1.16.1c: Development of Static Evaluation Procedures**
**Expenditures:$21,000**

As part of the overall program to identify and evaluate techniques for predicting the potential for tailings and waste rock to produce contaminated run-off and seepage, further applicable static procedures were identified and assessed. Based on a review of the chemical literature, four methods were ranked by, among other parameters: cost; rapidity and robustness; and selected for preliminary testing using samples of known mineralogical composition. The methods tested were: determination of sulphur as pyrrhotite and pyrite; field determination of sulphur as pyrite; modification of the conventional U.S. EPA neutralization potential procedure by filtration of leachate and addition of hydrogen peroxide; and determination of carbonates by metal analysis. The first procedure performed well but further development of the latter three was considered necessary. Methods to directly and quantitatively determine Ca and Mg carbonates are not commercially available and modification of the third procedure is recommended to address this problem. It was underlined that routine acid-base accounting should include a supporting mineralogical description to provide confidence in the predictive chemical results.

**Project 1.17.1: Hydrogeochemical Investigation - Waite Amulet Reactive Tailings**
**Expenditures:$285,000**

This multi-year hydrogeochemical baseline field study was designed to develop a better understanding of the hydrology and hydrogeochemistry occurring in acid-generating tailings ponds. The data were also collected to be used to assess or refine existing predictive models (1.21.1a) and provide guidance in the development of new models and control techniques. Preliminary site reconnaissance along with piezometer installation and sampling of tailings and porewater allowed an assessment of the tailings and underlying hydrogeologic characteristics such as porewater chemistry, water table and tailings depth, mineralogy, hydraulic conductivity, direction of flow, and biological activity data. Further data collection completed the definition of the site hydrogeology. The unsaturated zone geochemistry under clay covered, directly vegetated and untreated sites and along the dam face was evaluated. Oxidation control options were defined. A water and metal balance for the tailings site was completed by monitoring precipitation, evaporation, and the flow and quality of the seepage at the face and the surface. The mineralogy of the unsaturated zone was defined and

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related to porewater chemistry using computer models. Oxygen diffusion versus depth into the tailings was determined. The study verified that the most important control on pyrite oxidation is the availability of oxygen, which influences production of ferric iron and bacterial population density. Oxygen diffusion was considered horizontally as well as vertically.

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**Project 1.19.1: Kinetic Test for Cinola Gold Project**
**Expenditures:$94,360**

This project involved the continuation of some of the long-term predictive testing of waste rock initiated for the Cinola Gold property in 1988 by City Resources. Specifically the objectives were to: · characterize 6 years of acid generation trends from four on-site waste rock pads;

- evaluate a column study of mixing calcareous rock with waste rock;
- characterize material that has undergone over 3 years of humidity cell weathering; and
- compare and evaluate various predictive methods used.

Some of the more advanced and long-term work in prediction of acid mine drainage has been conducted for the Cinola Gold Project (Queen Charlotte Islands, B.C.). These tests included: acid-base accounting (ABA); humidity cells to examine the long-term acid production potential of marginal material (as defined by ABA); shake flasks to test short-term acid release; column experiments to investigate the effect of limestone blending; and field waste rock piles to study the relationship between laboratory and field acid production.

Leachate from the 4 waste rock pads were monitored through 1993 and material from one pad was sampled to analyze the extent of weathering. Of the 5 columns containing waste rock and varying percentages of limestone, only the column with a Neutralization Potential/Acid Potential (NP/AP) ratio > 1 generated pH-neutral water throughout the 5 year experiment. However, based on leachate data this column was also predicted to go acid. The columns were dismantled in late 1993.

**Project 1.21.1a: Evaluate RATAP.BMT2 Capabilities**
**Expenditures: $30,000**

Originating from work in the mid 1980's by CANMET, the Reactive Acid Tailings Assessment Program for Base Metal Mines (RATAP.BMT) was developed as a predictive modelling tool to: investigate the parameters which control sulphide mineral oxidation in tailings; simulate such acid generation; estimate acid generation potential in the long term; and evaluate control measures. The capabilities and limitations of the RATAP.BMT2 model were evaluated, including calibration of the model using Waite Amulet field data (1.17.1) and critical assessment of the concepts on which the model is based. Part of the data was used to calibrate the site dependent parameter estimates and the rest to verify the model both in the temporal and spatial sense. Modifications were made to the model where required. The modelled constituents included: temperature; pH; oxygen concentration with depth; and porewater concentration of sulphate, ferrous and ferric iron, dissolved copper and zinc. The model has been reviewed further (1.21.1b) and a manual has been generated (1.21.1c) for the current version of the program (RATAP.BMT3).

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**Project 1.21.1b: Workshops of Modelling Techniques - Tailings**
**Expenditures: $73,000**

An international workshop was held on modelling of reactive tailings, to assess the current capabilities and the perceived requirements (industrial, regulatory). The workshop was held in Haliburton, Ontario on May 23 & 24, 1990, and was attended by participants from Canada, Sweden, United States, and Australia, representatives from the mining industry, the consulting community, universities and various governmental departments. The presentations and discussions concentrated on the simulation model, RATAP.BMT2, capable of calculating the generation of sulphuric acid from reactive tailings. Other presentations provided a consulting engineering perspective, the industry perspective and the point of view of the regulatory agencies for the use of models. Finally, representatives of the United States, Sweden and Australia presented their assessment of current capabilities. The use of programmed models capable of calculating the characteristics of reactive tailings and their impact on the environment was discussed. It was recommended that the RATAP.BMT2 model should be made available to potential users for evaluation before additional development of the model. It was also recommended that a user's manual should be prepared and made available with the model (1.21.1c).

**Project 1.21.1c: Modelling of Reactive Tailings - Prepare RATAP Users Manual**
**Expenditures: $19,000**

The mathematical model, Reactive Acid Tailings Assessment Program (RATAP), was designed to predict, in the long-term, the quantity of acid generated by oxidation of pyrite in uranium mill tailings. This model was adapted to base metal tailings. At the international modelling workshop held in May 1990 (1.21.1b), it was recommended that the model be prepared for distribution to potential users. RATAP.BMT3 is a complex model with over 250 input parameters, not lending itself to easy use. Therefore a module to facilitate inputting initial condition data and a second module to facilitate the acquisition and display of output data from model simulations were developed. This combination provides a powerful user-friendly predictive tool. A user's manual was prepared for the software ensemble. As recommended, an overview document has been prepared for RATAP.BMT3 to assist the potential user. This has been prepared, not as a separate document but as part of the input module, giving an overview of the models intended purpose and applications, estimated simulation capabilities, limitations, and expansion potential.

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Both model and manual are being distributed through the Canada Centre for Mineral and Energy Technology (CANMET).

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**Project 1.24.1: Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps.**
**Expenditures: $21,000**

The project was originally scoped to follow the complete development and abandonment of a 15 million tonne dump, over the course of four years. A variety of factors led to a much reduced scope of work, although it was recommended that the predictive modelling of AMD from waste rock be pursued. Collection and description of selected drill core samples from the Yukon (Curragh Resources) were carried out on site for dump material characterization. Key physical and chemical parameters were generally identified for the monitoring of reactive waste dumps. A conceptual model of the physical and geochemical nature of waste dumps was developed based on the existing literature and the incorporation of the parameters above. The development of such a model was recommended and would guide future assessment and design of instrumentation requirements for reactive waste rock dumps (1.26.1). The complexity of the modelling effort and potential scope of the study has however, been recognised.

**Project 1.25.1: Development of a Soil Atmosphere Flux Model for Design of Sulphide Tailings Cover Systems - Phase I**
**Expenditures: $55,800**

The objective of this project was to develop a computer program to calculate the moisture fluxes between tailings, cover systems and the atmosphere based on routine climate data and soil properties. Carefully designed soil cover systems may be used as oxygen barriers in the control of acid mine drainage; the success of which will depend on climatic conditions and cover system properties. A mechanistic tailings-cover-atmosphere flux model for evaluating the flux boundary conditions and the soil-atmosphere interface was developed at the Universities of Manitoba and Saskatchewan. The mathematical derivation and formulation of the finite element solution for coupled heat and mass transfer in soil covers has been successfully completed at the University of Saskatchewan. The Soil Atmosphere Flux model is compatible with PC/DOS computers. The program has been tested by comparing its solution with those computed by other well-established methods.

The University of Saskatchewan will continue with the development of the model to accommodate water flow and hydraulic effects under freezing conditions. Field data for this work will be collected from a mine site in British Columbia.

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**Project 1.26.1: Development of a Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock - Phase I**
**Expenditures: $90,000**

The primary objective of this project was to develop a preliminary model based on the current state-of-the-art for predicting drainage water quality from waste rock dumps using existing theoretical and empirical relationships. Inherent in that objective is the determination of the level to which a waste rock model can be developed to predict numerical values for the water chemistry of drainage from waste rock piles.

The report separates physical and chemical processes into 10 component models. For each of these components a description of the significance, current understanding, and recommended development is described. The report recommends that first priority be given to further development in the areas of; geochemical characteristics, physical characteristics, hydrogeological, and pile water quality, with the geochemical characteristics being given highest priority. Other areas of secondary emphasis are; pile geometry, pile base mixing, groundwater plume, downstream water quality, temperature, and oxygen (pore gas). The recommended developments addressed specifically by the proponents involved site assessment, mathematical simulation of rock pile construction, hydrological/hydrogeological modelling and specific humidity cells. The report recommends that effective development of the proposed 'applied modelling methodology' is currently the only viable basis for prediction, thus allowing for practical decision making regarding ARD impact and control.

**Project 1.31.1: Geochemical Study of Weathering Employing Secondary Ion Mass Spectrometry**
**Expenditures: $98,600**

The main project objective was to assess the applicability of Secondary Ion Mass Spectrometry (SIMS), Auger Electron Spectroscopy (AES), and X-Ray Photoelectron Spectroscopy (XPS), in defining compositional changes occurring in the upper angstroms of mineral surfaces as a result of weathering. Advantages and disadvantages of the three surface analytical techniques are presented. A parallel program involving surface analytical assessment of weathered and unweathered material, and conventional ARD prediction column tests were conducted. A direct comparison of naturally and artificially weathered surfaces to determine the predictive capacity of different humidity cell leaching regimes was not possible.

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The sulphide mineral size and content in the tailings and waste rock samples employed proved to be insufficient for the application of SIMS. Static and kinetic tests as well as whole rock, elemental and petrographic analyses were carried out on tailings from Echo Bay's Lupin Mine in the Northwest Territories and on waste rock obtained from Inco's Thompson Mine in northern Manitoba. Although direct comparison of naturally and artificially weathered material to assess predictive tests was not addressed, such a comparison may warrant further attention.

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**Project 1.32.1:** **Prediction and Prevention of Acid Rock Drainage - A Geological and Mineralogical Approach**
**Expenditures:** **$73,000**

The three main objectives of this project were to determine the tendency of major types of metallic sulphide deposits to generate acid, the relative oxidation rates of individual sulphide species in polysulphide assemblages, and the initial field measurements and laboratory analyses needed to assess the acid generation potential and expedite environmental impact assessment. Considering a literature survey and supplementary field investigations, seven common types of metallic mineral deposits occurring in western Canada are ranked according to the potential for development of acid rock drainage (ARD). The deposit susceptibility is based largely on the net acid-generating potential of the prevalent mineral assemblages, the accessibility of the reacting minerals to weathering agents, and potential mediation by iron-oxidizing bacteria. A formula for assessing acid rock drainage potential based on field estimates of mineral abundance is suggested in the report. Detailed examination of the prevalent sulphides indicate the importance of trace element composition in affecting the stability of individual sulphides. It is therefore suggested that a general weathering sequence for the common sulphides may not exist except on a local scale. The report recommends that field geologists be trained to collect and interpret mineralogical and geological data and be involved in acid rock drainage assessment at every stage of a mining project. The report suggests a practical checklist for field assessment of ARD potential during mineral exploration and tasks at various phases of a pre-mine development are briefly discussed.

**Project 1.41.1:** **International Waste Rock Modelling Workshop**
**Expenditures:** **$7,770**

A three day international workshop on modelling the generation and transport of acid rock drainage from mining waste rock was hosted by MEND in late September 1992. Its purpose was to focus research and development of modelling capabilities for waste rock dumps to the needs and requirements of users by identifying: current (international) capabilities and shortcomings; and industry/regulatory requirements. It was suggested that a useable model should incorporate the following: oxygen and heat transport; solute movement and hydrology; and geochemistry. Oxygen and heat transport can be modelled although additional field assessment of relevant parameters was recommended. The area of solute transport and hydrology under mainly unsaturated conditions is less advanced. The geochemical processes are considered the most difficult, and in some cases simulation may not be possible. Among other actions, a critical review of the key geochemical processes and associated current modelling capabilities (1.42.1) was recommended to assess the potential for incorporation of geochemistry into the overall predictive capacity. The workshop proceedings are available through the MEND Secretariat.

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**Project 2.11.1a-c: Evaluation of Existing Underwater Disposal Sites**
**Expenditures: a: $220,000 b: $136,000 c: $67,625**

The objective of this project was to evaluate the effectiveness of underwater disposal of reactive wastes by evaluating representative existing sites, examining the impacts which result when in-lake disposal systems are used, and recommending criteria for the safe underwater disposal of tailings. Initially (2.11.1a), all known Canadian sites were documented and water quality results were obtained from existing sources (1988/89). Field surveys were done on 4 sites during the summer of 1989 (Buttle and Benson Lakes in B.C., Anderson and Mandy Lakes in Manitoba). Geochemical assessments were conducted at Anderson and Mandy Lakes in Manitoba in 1990 (2.11.1b). Two projects were completed on Benson Lake in 1991-1992. The first project focused on the chemical and biological aspects of changes in Benson Lake following subaqueous tailings disposal. The second project used Keogh Lake, a pristine, hydrographically similar "control lake" to permit geochemical comparison between lakes with tailings and without tailings.

**Project 2.11.1d: Peer Review on the Subaqueous Disposal of Tailings**
**Expenditures: $34,350**

At the request of the MEND Board of Directors, a scientific and technical review of all aspects of the work to date was recommended (2.11.1d). The future direction of the subaqueous tailings disposal program will be based on the results of the peer review.

The objectives of this project were to provide technical and scientific assessment of MEND studies on subaqueous disposal of tailings, and to outline additional requirements necessary for the MEND studies to maintain a credible scientific approach. The Peer Review was carried out by The Rawson Academy of Aquatic Science with the aid of highly qualified and experienced scientists, each a specialist in one or more fields of science dealing with aquatic ecosystems. The reviewers agreed that the work carried out to date on the three lakes reviewed, Mandy, Anderson and Buttle (Benson was not reviewed because work there was not complete) was well done. The review identified key areas that are lacking in information. For instance, the studies of background limnologies for the lakes were not suitable to present to regulatory personnel, the seasonal and yearly changes that occur in the water column loadings would have to be addressed and the field experiment for metal flux measurements, although well done, does not assess the quantitative fluxes which are considered important. Some additional literature reviews (e.g. metal toxicology) and a complete program for documenting QA/QC were suggested and the definition of the types of additional field data (e.g. geochemical) and methods for data collection were presented in the report. Additional work to develop a more complete understanding of the sites under study was recommended.

**Project 2.11.2a: Literature Review Report: Possible Means of Evaluating the Biological Effects of Subaqueous Disposal of Mine Tailings**
**Expenditures: $16,300**

One of the recommendations made in the Peer Review (Project 2.11.1d) was that "selective and additional literature reviews" be undertaken on the biological uptake of metals, their bioaccumulation, and their possible toxic effects on aquatic organisms. The objectives of this study was to respond to this recommendation. Given the extensive literature available on metal-organism interaction, the focus was on the possible biological effects of subaqueous disposal of mine tailings. The basic premise has been that mine tailings and their constituent metals, may affect aquatic life in two ways: indirectly (i.e. by leaching of the metals into the ambient water, followed by their assimilation from the aqueous state), and directly (e.g. in macrofauna, by ingestion of the tailings and assimilation of the metals). Both routes were considered. This review identifies promising geochemical and ecotoxicological approaches that might be used to monitor the biological effects of the subaqueous disposal of reactive mine tailings.

**Project 2.14.1: Establish Vegetative Wetlands over Tailings**
**Expenditures: $30,000**

The objective of this project was to develop a technique for the reclamation of high iron sulphur tailings by establishing a marshland or perched water table above the tailings. The project was initiated in 1986, when a total of 9 test cells with different surface covers and amendments were constructed at the Fault Lake tailings site in Falconbridge. The covers were kept wet and the porewater quality and metal loading of the unoxidized tailings were monitored for three field seasons. Two important recommendations resulted from this study: first, to establish a marshland or perched water table above the tailings, one must define the hydrology of the site to define the water table and the groundwater fluctuations; and second, one must determine the hydraulic conductivity and gas permeability of the tailings. In these trials, coarse tailings resulted in high water/gas permeabilities and a perched water table could not be maintained without continuous irrigation.

**Project: 2.21.1:** **Engineered Dry Covers for Tailings**
**Expenditures:** **$216 000**

The objective was to develop laboratory and computer methodologies for testing, designing, placing and evaluating the effectiveness of engineered soil covers for reactive sulphide wastes. Practical concepts were proposed for designing high performance soil covers using locally available natural materials. Critical material properties required for design and prediction of performance were identified and these were obtained using specially designed laboratory columns. A computer model describing oxygen diffusion in soil covers was also developed and is currently being used in the demonstration column work for different cover projects (e.g. large scale tests at Waite Amulet (2.21.2) and Heath Steele (2.31.1)). These evaluation techniques and standardized laboratory procedures will permit the testing of candidate soils from which the full-scale results can be modelled and predicted.

**Project 2.21.2:** **Engineered Dry Covers for Tailings - Noranda**
**Expenditures:** **$532,800**

The objective of the project was to design, construct and evaluate the effectiveness of engineered soil covers in preventing and controlling acid generation in reactive mine tailings. A total of four test plots were constructed at the Waite Amulet tailings site, consisting of two composite soil covers with a compacted clay layer sandwiched between a fine and coarse sand layer, one geomembrane cover and a control (tailings without cover). These were instrumented to measure gaseous oxygen concentrations, water content, suction, temperature and porewater quality at various depths. Coincidental with the field work, six columns were installed in the laboratory to simulate soil-covered and uncovered tailings. Gaseous oxygen concentrations, water content, temperature and drainage water quality were measured over time.

Results of the laboratory, field and modelling studies indicated that the oxygen flux is reduced by 91 to 99% by the soil cover. Monitoring of acid fluxes over time suggested that the rate of acid production decreases with time. Hydrologic modelling indicated that water percolation through the cover is about 4% of precipitation compared to 6% in the field tests (80% reduction). The effects of freeze-thaw on the integrity of the compacted clay layer showed that freezing and thawing have not adversely affected the cover.

### Project 2.22.1: Assessment of Hardpan

**Expenditures: $100,500**

The project was designed to characterize the mineralogy of hardpan and to assess if it can be stabilized and used as an oxygen barrier. Petrographic studies and permeability tests were conducted on selected hardpan samples from four Manitoba tailings sites. The general properties of hardpan were initially found to be encouraging as a relatively impervious and resistant zone was observed. Weathering and seasonal frost, however, tend to break down the hardpan, resulting in a fractured, softened zone which possesses only moderate resistance to infiltration and continuous oxidation. As a result, serious doubts remain concerning the use of hardpan to control the acid generation process. Also, no suitable method of artificially creating hardpan was determined and the project was terminated.

### Project 2.23.1 Documentation of Disposal Methods for Tailings and Waste Rock (Draft Acid Rock Drainage Technical Guide)

**Expenditures: $75,000**

A comprehensive manual was prepared which provides an introduction to acid rock drainage (ARD) and direction on how best to deal with the problem. Techniques are discussed with respect to the handling of waste rock, tailings, open pits and underground workings. Current approaches in other parts of Canada and the world are also described. The manual has been prepared as a "how to" document and is being

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distributed in loose leaf binder format so that the manual can be easily updated in the future. The BC AMD Task Force recommended that the monitoring section (Chapter 11) of the Technical Guide be upgraded to incorporate recent developments in monitoring techniques, sampling equipment, data manipulation and statistical treatment (4.5.3)

**Project 2.23.2ab: Hydrogeological and Geochemical Analysis of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines**
**Expenditures: $155,700**

The objective of this two-year study was to measure the hydraulic properties of the TTD tailings site to analyze their effects on the long-term impacts to the environment. Noranda carried out a field evaluation of the principal components of the site hydrology to obtain a verification of the high moisture retention of the TTD deposit. The field program included measurements of moisture content, hydraulic head, water table elevation, hydraulic conductivity, precipitation, pan evaporation and evaporation. Porewater was sampled and analyzed for major metal and ion concentrations. The result from measured physical characteristics inferred the presence of a significant capillary fringe above the water table. The analysis of porewater indicates that sulphide oxidation is occurring. However, low porewater velocities and near-surface saturated conditions will ensure that contaminants released to the environment will remain at the present rates, which is low, even after mine closure. The study suggests that the TTD method seems to be advantageous because of the low dissolved metal fluxes to the environment.

**Project 2.24.1: Vegetation Manual "Manual of Methods used in the Revegetation of Reactive Sulphide Tailings Basins"**
**Expenditures: $33,500**

The manual provides a comprehensive description of procedures for preparation, neutralization, seeding and follow-up maintenance, if required, for revegetation of reactive sulphide tailings disposal areas in Canada. It describes and illustrates some of the more common agricultural equipment and fundamental, basic techniques required to prepare, seed and maintain mine waste areas revegetated. Case histories are appended that outline reclamation programs carried out at several Canadian mines including Falconbridge, INCO and Noranda.

**Project 2.31.1a: Dry Covers on Waste Rock - Heath Steele**
**Expenditures: $312,000**

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Acidic drainage generation in waste rock poses a much different problem from that of tailings because of the huge difference in the particle sizes of the waste material. Waste rock piles contain large voids which allow water and air to freely penetrate the pile and these conditions promote accelerated bacterial and chemical reactions. The objective of the project was to evaluate the effectiveness of engineered natural covers for reactive sulphide waste rock at the Heath Steele mine site. Locally available cover materials were sampled and characterized according to standard soil properties. A column apparatus was used to measure the rate of oxygen diffusion through potential cover materials (2.21.1). Based on the results of the laboratory testing a practical, composite cover was designed using native materials. In order to confirm the effectiveness of the proposed cover it was recommended that the cover be field tested (2.31.1b).

### Project 2.32.1 Blending and Segregation of Waste Rock - Kutcho Creek

**Expenditures: $ 140,000**

The objective was to evaluate, through laboratory and field analysis, the effectiveness of segregating and blending acid-generating waste rock and alkaline material as a method of preventing or controlling AMD. Acid-base accounting tests were used to identify the materials and humidity cell tests composed of blended ratios demonstrated that the rate of acid generation was reduced. Results from the test pads were not as conclusive as the laboratory results. It was discovered that leachate quality was dependent upon flushing rates as opposed to the actual acid generation rate. Long-term predictions, based on the results from the humidity cell test work, show that the neutralizing potential could be consumed in as early as 100 weeks with acidic conditions continuing until all sulphides were oxidized. A separate analysis has determined that the costs associated with blending large amounts of waste materials in a full scale waste dump would be excessive. Based on these predictions, blending of Kutcho waste rock, even at 1:1, would not be a viable option. No follow-up work was recommended.

### Project 2.32.2a Co-Disposal of Tailings and Waste Rock in Cells - Les Mines Selbaie

**Expenditures: $96,000**

The objective of the project was to evaluate the concept of co-disposing reactive sulphide waste rock with non-reactive tailings in basins to minimize acidic drainage from the waste rock. The design seeks to create saturated conditions in the reactive waste and minimize groundwater flow in the basin. Phase (a) consisted of field reconnaissance, characterization of both tailings and waste rock and potential basin construction materials, and a preliminary geotechnical design of the basin. The prediction tests carried out on the tailings materials indicated that the tailings are likely

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to generate acid. The project was based on the concept of co-disposing acid-generating waste rock with neutral tailings. Since the tailings are likely to be acid producers, the final design of the basin was changed to rely on low permeability dykes to maintain saturated conditions in the waste rock and tailings. This was not the original concept and no follow-up work was recommended.

### Project 2.33.1 ARD Remediation Measures at Four Norwegian Mines

**Expenditures: $38,500**

The project was undertaken to provide a transfer of information of full-scale remediation measures used at four sulphide mines in Norway. The study addresses operational difficulties, procedures, results and costs of natural sulphate reduction (Lokken mine), natural convection as an evaporative treatment process (Killingdal mine), geomembrane covers (Kjoli mine) and underwater disposal (Skorovas mine). The final report makes conclusions and recommendations about the remediation methods used at the four sites.

### Project 2.41.1a: Electrochemical Oxidation/Passivation of Sulphides

**Expenditures: $60,000**

The objective was to develop electrochemical methods for the prevention of atmospheric oxidation, acid generation and leaching of sulphide tailings. In this project, it was established that a passive iron oxide film grown on pyrite/pyrrhotite can protect the substrate from oxidation on exposure to air and hence prevent acid generation. It was also shown that a bed of pyrrhotite rich tailings can be converted into a hardpan by a cathodic treatment followed by exposure to air under moist conditions. Six weeks after switching the current off, the bed automatically consolidated into a hardpan with some expansion. The solution percolating through this bed in the earlier stage of hardening had a pH of 5.5 and the iron concentration was lowered to natural equilibrium values. Following a progress review meeting, it was recommended that the project not continue to larger scale tests. However, the concept of in situ formation of synthetic hardpan by surface chemical treatment, briefly presented in Phase I, was recommended to the New Ideas Task Force for consideration. An additional project was completed under New Ideas but did not show economic potential.

### Project 2.44.1: Microbial Plugging of Mine Tailings to Reduce the Production of AMD

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**Expenditures: $100,000**

The objective of the project was to evaluate, at a laboratory scale, the microbial plugging technology as a method of reducing the production of AMD. The project involved the use of starved indigenous microorganisms called ultramicrobacteria's (UMB's) which, when exposed to nutrients, reproduce and excrete polymers. The polymers fill the void spaces in the tailings, effectively creating a microbial plug capable of reducing both the penetration of oxygen and water. The conclusions of the study were that: it was not demonstrated that a microbial cap could significantly reduce the permeability of the tailings over long periods of time; a decrease of the oxygen penetration was observed for the columns that received nutrients; an increase in pH was observed for all of the permeates from the columns that received nutrients; and addition of UMB's to the tailings was not necessary because native strains were present in the tailings. It was also noted that although a reduction in permeability was not observed in the experiments, it is possible that in fine textural tailings, a significant reduction in water permeability would be expected. No follow-up work was recommended.

*TREATMENT*

### Project 3.11.1a-c: Treatment of Acidic Seepages Employing Wetland Ecology and Microbiology - Phases A, B and C

**Expenditures: $679,000**

This project was designed to investigate the use of microbiology and ecology of wetlands to reduce acid mine drainage. A major objective was to develop design parameters for the Acid Reduction Using Microbiology (ARUM) process. The project had the following phases: a), Conduct microbiological nutrient requirements and cellulose degradation studies in the laboratory, and set up field systems at Elliot Lake and Copper Cliff, Ontario; b), Microbiological and water quality monitoring and conduct process capability tests; c), Monitor system performance and make final adjustments; and d), Monitor and establish performance criteria for operating systems.

The key results related to water quality; significant alkalinity was created (27 kg/tonne of water) and the heavy metals were precipitated as sulphides. However, the system appeared to be capable of handling only low flows, less than 3 to 5 litres/minute. At the very low flow of 1 litre/minute, very good water quality had been produced. The Treatment committee carefully reviewed the results achieved to the end of 1991 and recommended that the final year's monitoring and determination of performance criteria be completed (3.11.1d).

### Project 3.11.1d: Treatment of Acidic Seeps Employing Wetland Microbiology (ARUM)

**Expenditures: $80,000**

The final report entitled: "Treatment of Acidic Seepages Using Wetland Ecology and Microbiology: Overall Program Assessment" summarized the field observations and measurements over 4 years in the field at Sudbury, determined the operating parameters for the ARUM system, produced design criteria and conceptual design, and estimated operating costs. The results showed that some very good water quality results had been achieved at a flow rate of 1 litre/minute. However, it appears that the system is not suitable for final treatment of large flows, but rather is applicable for pre-treatment in advance of an engineered treatment system. This will reduce costs by generating alkalinity and by precipitation of some of the metals. It could also be used for small seeps, or part of a package involving dry covers to reduce effluent flow rates. Considerable research and process development has been done on passive systems for treatment of AMD. The studies, including the ARUM process, have demonstrated that the use of passive systems to treat acidic seepages is technically feasible but that the performance and the applicability of these systems remain uncertain. The main problems are low capacity, fouling and high retention times needed.

### Project 3.12.1: Assessment of Natural Wetlands Affected by Low pH / Metal Contaminated Seeps

**Expenditures: $40,000**

The study examined natural wetlands near six base metal mines in Eastern Canada for evidence of biological mitigation of acidic drainage. Potentially suitable wetlands were identified and a field program was conducted to describe and compare these sites in terms of water and sediment chemistry, hydrology, and vegetation. The project was started too late to conduct a summer campaign; only autumn results were obtained. There were large differences between the wetlands in terms of metal loadings, groundwater inputs, water retention times, metal concentrations in wetland sediments, and vegetation communities. None of the sites, however, appeared to significantly reduce downstream loadings of metals or acidity levels during the fall. Prolonged drought at one site severely reduced flows and prevented the calculation of influent and effluent metal loadings. The apparent lack of biologically-related improvement of AMD was most likely a consequence of (1) low temperatures, ca. 4°C, (2) channelized flow patterns within the wetlands, and (3) limited contact of acidic drainage with anoxic sediments. Inputs from other seeps and groundwaters to the wetlands were significant complicating factors, especially at the Kam-Kotia site. High metal concentrations in wetland sediments indicated that the wetlands had removed metals in the recent past.

### Project 3.12.2: Evaluation of Wetlands at Panel "A" Site

**Expenditures: $45,000**

This study was completed to establish if a beaver-constructed natural wetland at Elliot Lake provides significant treatment and control over water quality parameters associated with the oxidation of pyritic tailings and control of contaminant migration. A final report entitled: "Panel Wetlands: A Case History of Partially Submerged Pyritic Uranium Tailings Under Water" provides detailed information on surface and groundwater hydrology, chemistry, water balance and their seasonal variations, solid phase characteristics of sediment/substrate, bacterial enumeration and vegetation uptake of metals in the basin. The survey results have confirmed that the wetland/water cover system in the Panel wetlands basin is effectively controlling the acidic drainage from partially submerged pyritic uranium tailings. It is concluded that the system would continue to function as long as the water cover is maintained and its performance could be further improved if all the tailings were completely submerged (a small proportion remains uncovered). This study confirmed that shallow water covers in combination with a natural wetland have potential to permit "walk-away" with minimal maintenance at some tailings sites.

*TREATMENT*

**Project 3.21.1a: Metals Recovery from Acid Mine Drainage - Phase A**
**Expenditures: $25,000**

A background survey and a review of technology were completed on methods which could remove metals such as Cu, Ni, and Zn from acidic drainage and reduce the potential toxicity of treatment sludges. A summary report was completed in November 1991. Three technologies were determined to have economic and technical potential. They were; copper cementation, ion exchange, and selective precipitation. Since cementation is a well defined and frequently used method, ion exchange and selective precipitation of metals were the methods recommended for further research. These methods were assessed in projects initiated in 1992. It was indicated that a cross-Canada survey of acid drainage water quality was needed (project 3.22.1).

*MONITORING*

### Project 4.1.1: Field Methods Manual - Tailings

**Expenditures: $29,000**

Accurate monitoring of a tailings impoundment requires that the samples collected for physical, chemical and microbiological analyses be of high quality. A manual of sampling methodologies applicable to tailings impoundments and involving the collection of representative solid, liquid and pore-gas samples was prepared. It offers guidance and recommendations on the selection of methods, emphasizing minimal sample disturbance and contamination. For each method, the objectives, descriptions, advantages and disadvantages are presented. Flowcharts are presented to summarize the methods and guide in their selection. A summary of quality control recommendations defined in the three primary chapters is also presented.

### Project 4.2.1: Decommissioning Criteria

**Expenditures: $15,000**

The objective of the project was to review Canadian and United States legislation relevant to decommissioning acid mine drainage sites. The purpose of the review was to provide government agencies, industrial representatives and other organizations and individuals with an overview of the existing Canadian and United States regulatory framework relevant to decommissioning AMD sites and to summarize the criteria used by Canadian and United States regulatory agencies to assess the performance of a decommissioning AMD site. In general, regulatory strategies specific to decommissioning AMD sites are still in the development stage both in Canada and the United States. The criteria that would typically be used in assessing a site are effluent quality leaving the mine site and groundwater and surface water quality downgradient. Effluent limitations, drinking water standards and surface water quality criteria have all been developed at a federal level by the United States EPA. In Canada, non-enforceable water quality guidelines or objectives are prevalent, with enforceable site specific parameters incorporated into mine operation permits or licences. Apart from the federal guidelines, those of the provinces and territories in Canada were also covered, while for the United States, the review concentrated on the following seven states: Idaho, Nevada, California, Montana, Colorado, Pennsylvania and West Virginia.

*MONITORING*

### Project 4.3.1: Standard Reference Materials - Tailings
**Expenditures: $50,000**

The key to reliable and reproducible analytical results is the availability of good, relevant standard reference materials. CANMET has an established Canadian Certified Reference Materials Program (CCRMP) through which four mill tailings materials were selected, prepared and certified. The four samples were prepared as composite reference materials from pyrite/pyrrhotite tailings from INCO, Falconbridge and Noranda. Analyses of nineteen major and minor elements were performed by seventeen laboratories on six replicates for each of the four standard materials. The reference materials, RTS-1, RTS-2, RTS-3, and RTS-4, are currently available through CANMET with all applicable supporting documentation.

### Project 4.5.2: Field Sampling Quality Assurance/Quality Control (QA/QC)
**Expenditures: $9,500**

A literature review has been completed on field sampling criteria with particular emphasis on quality assurance and quality control protocols. The focus is on components of programs for predicting or detecting acid mine drainage and its environmental effects. Data quality objectives must be set which define the level of uncertainty that a decision maker is willing to accept. The report reviews the elements of field QA/QC programs for sampling surface and groundwater, effluents, sediments, soils, tailings and waste rock for chemical parameters related to AMD. It also reviews QA/QC programs for: stream flow measurements and biological effects monitoring, including sampling populations of fish, benthic invertebrates, periphyton, zooplankton, and phytoplankton; metals in fish tissue; and the presence of *Thiobacillus ferrooxidans*. Although the elements of QA/QC programs for laboratory analyses are reasonably well defined with respect to the assessment of acid mine drainage it is recommended that more emphasis be placed on the implementation of QA/QC protocols for field programs.

## *MONITORING*

### Project 4.6.2: Continuous Monitoring of AMD - Literature Review
**Expenditures: $50,000**

This project aimed to identify and evaluate the capability of commercially available continuous monitoring technologies to address the monitoring requirements of AMD sites in Canada, and to identify the advantages and disadvantages of continuous vs. manual monitoring. An international survey of commercially available monitoring equipment (selective ions, redox potential, dissolved oxygen, pH, electrical conductance, etc.) applicable to AMD resulted in a list of just over 50 manufacturers. The identified equipment was divided into three categories: physical parameters (pH, dissolved oxygen, temperature etc.); chemical concentrations (Cu, Fe, As ions etc.); and meteorological conditions (precipitation, wind etc.). The evaluations and appended information focused on integrated commercially available continuous monitoring instruments. Five systems were identified which addressed the physical parameters while only two of these also monitored selected ion concentrations. One system, PIRANA, was recommended as most applicable. Actual expected detection limits, precision, maintenance requirements, cost and so on, were not addressed for AMD specifically and may be expected to vary considerably between sites. The concept of detailed data collection at an AMD site over a finite period to assess trends and potential correlations is considered worthwhile in the development of a focused, long term monitoring program. However, the specific application of the PIRANA system, as recommended in the report, is not being considered at this time.

### Project 4.7.1: Optimum Sampling Frequency
**Expenditures: $27,000**

The project objective was to determine optimum water quality sampling frequencies and most representative, measurable parameters (e.g. pH, conductivity) for AMD effluent by evaluating four of the most extensive water quality data sets associated with acid mine drainage in British Columbia. A number of potential failings were discussed, including: fixed-frequency single samples used in mean loading estimates; inaccurate or incomplete flow estimates; significant short-term events; and the overemphasis of analytical accuracy versus timely, representative sampling. It is recommended that acid mine drainage monitoring schedules be revised to consider the information needed for management; i.e., accuracy, lag times, risks, and parameter variation (spatial and temporal). As well, pre-operational studies at proposed mine sites should include measures of natural

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variation and should span seasons of anticipated high acid mine drainage discharge to obtain adequate baseline data.

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### Project 4.7.2: Biological Monitoring of Acid Mine Drainage

**Expenditures: $21,000**

The objectives were to determine the most effective methods for biological monitoring of acid mine drainage through a review of existing methods and assess and recommend the most effective techniques. A variety of indicators are suitable for detecting impacts of AMD, but few have been linked to chronic whole organism responses. The most promising and proven biological monitoring techniques, however, include: benthic community responses; growth and reproductive parameters of fish populations; survival in a designated zone of impact; and other changes at the individual, biochemical level. It was determined that no single approach to the problem of biological effects monitoring will completely satisfy present needs. The most cost-effective approach to assessing ecosystem health in waters affected by AMD was found to involve a multi-disciplinary, "top-down" approach, which relies on the detection of impacts before they become irreversible.

### Project 4.7.3: Aquatic Invertebrate Monitoring

**Expenditures: $136,130**

A three year research project was aimed at evaluating a trough apparatus for measuring the environmental effects of acid mine drainage on aquatic invertebrates. The study was carried out at Equity Silver in British Columbia to address allowable dilution rates of treated acid mine drainage that are discharged into Foxy Creek near the mine.

In the first year a flow-through trough apparatus was constructed to test pre-selected concentration of treated acid mine drainage. The apparatus accurately determined ecosystem response curves for effluent discharges as indicated in the available report titled "The Effect of Treated AMD on Stream Macroinvertebrates and Periphytic Algae: An in situ Mesocosm Experiment". Ensuing work involved monitoring chemical and biological changes in a stream mesocosm that was dosed with a gradient of AMD from Equity Silver. Among other conclusions, the report indicated that the metal concentration in solution which causes a change in community structure may be lower when that metal is part of a complex solution of metals. Models of indices of benthic response to the gradient of AMD additions were generated and compared to the CCREM guidelines.

*MONITORING*

### Project 4.7.4: Acid Mine Drainage Sediment Monitoring

**Expenditures: $6,500**

This project was designed to review all available literature pertaining to sediment monitoring techniques and to recommend the relevance and applicability of these techniques for measuring the impact of AMD. The review focuses on assessment of sediment quality through sediment chemistry, bioassay testing and benthic macroinvertebrate community structure. Analytical methods for sediment chemistry are reviewed and summarized. Sampling devices, design, handling and preparation are evaluated with respect to sediment toxicity testing. Freshwater sediment bioassays with bacteria, algae, invertebrates and fish are reviewed. Guidelines for sediment chemistry, bioassay testing and benthic macroinvertebrate community assessment are provided, while stressing proper QA/QC. The application of the Sediment Quality Triad approach is recommended. This approach was developed to utilize three measures of sediment quality: sediment chemistry, which measures contamination; sediment bioassay, which measures toxicity; and biological community structures, which measures biological alteration.

### Project 4.7.5: Ion Speciation

**Expenditures: $35,092**

The project objective was to provide estimates of the most probable species of a given metal, and their redistribution when raw AMD is mixed with receiving waters. Ionic speciation must be considered in the development of monitoring criteria and monitoring programs that attempt to predict the environmental impact of metals introduced into the environment. Toxicity of dissolved metals is dependant on the physical/chemical parameters associated with specific species. The model, described in the report titled "Evaluation of *B.C. Mine* for Application to Acid Mine Drainage Regulations", gives projections of metal speciation at any one point in time from a given location. Historical data on the site combined with total metal levels provide the basis for potentially using predictive modelling as part of the regulatory process. With the information provided, in terms of organic binding and free metal ion activity, it may be possible to provide increased metal into the system before biological impact is observed. In addition to this, metal metabolism of indicator organisms as a controlling system may be an important consideration. Development of the model *B.C. Mine* is not being pursued further at this time.

*MONITORING*

### Project 4.7.6: Paleolimnology Techniques

**Expenditures: $16,500**

The extent of an operation's environmental impact can only be determined with respect to original, baseline values. Long term studies may be necessary to establish baseline levels at existing mine sites. However, cost is often a prohibiting factor. The use of paleolimnology was therefore considered for describing past conditions including, for example, pre-mining conditions, at active or closed sites. Large scale studies in North America and Europe have successfully used paleolimnological indicators for effects of acid rain and these have been reviewed to evaluate whether similar techniques could be applied to AMD monitoring. The report, based on a literature review, concludes that it should be possible to develop a calibration data set which relates species assemblages of the chosen taxon to levels of AMD-related parameters. Currently there is no commitment to develop an appropriate calibration data set.

### Project 4.8.1: Monitoring of the Flooded Solbec Pit

**Expenditures: $136,500**

The objective of the three-year monitoring project was to assess the long-term effects of relocating waste rock into an open pit and subsequently flooding the pit for the control of acid generation. The Solbec mine is located in the Eastern Townships in the province of Québec. Acid generation and drainage from waste rock on the surface resulted in the contamination of surface water and high concentrations of base metals. In 1988, 276,000 cubic meters of highly oxidized waste rock were placed in the dewatered pit, covered with a 5 cm layer of limestone and reflooded to a water depth of 1.5 m as part of a control measure. Characterization of the pit followed by a detailed monitoring program has been undertaken to better understand the consequences of the chosen method of control on the surrounding environment. In the first year, the work included: mine site characterization; borehole placement (one upstream, two within the pit and two downstream); piezometer installation in the boreholes (the four latter, multilevel, the former, single level); and chemical analyses of solid and liquid samples from the pit and surrounding areas. The general hydrogeological regime for the site has been prepared using all information available. Based on the first year it was recommended that additional boreholes be placed downstream of the filled and flooded pit. A review of a proposed geophysical survey indicated that the Solbec pit area would be a good site for EM surveys given the resistivity of host rocks and the absence of both thick conductive overburden and interference from powerlines. Use of EM-31 and EM-34 coverage downstream and around the periphery of the pit has been recommended.

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**Project 5.1.1a-c: Provincial Workshops**
**Expenditures: $29,300**

During 1993 three workshops were held by MENDO, NEDEM-Québec and the B.C AMD Task Force. These technical sessions were well attended, demonstrating the strong continuing interest in the control of AMD by industry and government.

MEND Ontario (Sudbury, Ontario): 200 delegates; summary notes available.

NEDEM-Québec (Val-d'Or, Québec): 120 delegates participated in the "Deuxième Colloque NEDEM-Québec"; proceedings available (en français).

BC AMD Task Force (Vancouver, British Columbia): Second annual British Columbia Acid Mine Drainage Symposium; abstracts of proceedings available.

**Project 5.3.1,2: Laurentian Database**
**Expenditures: $35,000**

A bilingual database has been established as part of Laurentian University's Mining Environment Database. There are over 10,000 abstracted references to journal articles, books, government reports, and conference proceedings.

The database includes a complete bibliographic description of titles as well as abstracts. In addition, actual documents are available from the Laurentian Library for consultation or for borrowing through interlibrary loan. Access to the Laurentian database is free to anyone with a telephone modem/computer hookup and by Internet.

**Project 5.4.1: Acid Rock Drainage Technical Guide - version française**
**Expenditures: $23,700**

The Guide is a french version of the Draft Acid Rock Drainage Technical Guide. It provides the most comprehensive and easy-to-understand overview of the issue and technical aspects of acidic drainage (2.23.1). Increase in understanding of the issue, particularly in the mining industry, is a MEND priority. One hundred copies of the french version of Draft Acid Rock Drainage Guide were printed and seminars were held in Val-d'Or and Noranda to explain the guide.

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### Project 5.5.1: Preliminary MEND Research Plan

**Expenditures: $25,000**

The original plan (RATS) was produced in 1988. This plan called for an expenditure of $12.5 million over 5 years. In May 1991, the MEND Management committee requested that each of the technical committees produce a revised plan for MEND. The technical committees reviewed the progress to date; examined the priorities; produced a focused plan with distinct outputs; and defined an end to the program. The Revised Research Plan for MEND includes the decisions of the MEND Board of Directors to expand the program to $18 million total expenditure and to extend the program to the end of December 1997.

### Project 5.6.1: Second International Conference on the Abatement of Acidic Drainage

**Expenditures: $127,000**

The Conference was an outstanding success. Over 500 delegates from around the world attended the 3 day conference at the Sheraton Hotel in Montréal on September 16, 17 and 18, 1991. There were 134 technical papers presented in 15 different sessions. Also there were 3 days of poster sessions. Workshops were presented on September 14 and 15 and these workshops were well attended. There were field trips after the conference, to Bathurst, New Brunswick, to Noranda, Québec and to Elliot Lake, Ontario. MEND participants took the opportunity to present and listen to many of the excellent presentations, to meet many people from Canada and around the world, and to have several MEND technical committee meetings and to invite interested guests to these meetings. Many attenders commented that the conference was the best conference of any kind that they had ever attended. The proceedings (4 volumes) are available from the MEND Secretariat.

# APPENDIX C
## Recently Completed Projects

| Number | Titles: |
|---|---|
| 1.14.2 | Monitoring & Modelling AMD from Waste Rock: Mine Doyon Phase II |
| 1.16.2a | Prediction Test Standard Material: Interlaboratory Program for Characterization of the ARD Standard Material NBM-1 |
| 1.22.1 | Assessment of the ANSTO Gas Transfer Model at Heath Steele, Newcastle, N.B. |
| 1.41.2 | ARD Waste Rock Monitoring Database |
| 1.51.1 | Quantitative Analyses of Chemical and Biological Kinetics |
| 1.51.2 | Non-linear Modelling of Chemical Kinetics for Acid Mine Drainage |
| 2.11.3abc | Evaluation of Underwater Disposal Site - Anderson Lake |
| 2.13.1 | Flooding of Existing Tailings Sites - Quirke Lake |
| 2.13.2abc | Flooding of Existing Tailings Sites - Solbec Cupra |
| 2.13.3 | Flooding of Existing Tailings Sites - Falconbridge |
| 2.20.1 | Evaluation of Alternate Dry Covers for the Prevention of Acid Mine Drainage from Tailings |
| 2.23.2d | Geochemical Evaluation of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines |
| 2.23.3 | Porous Envelope Surround Disposal Method - Falconbridge |
| 2.25.1 | Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost |
| 2.25.2 | Design of an Organic Barrier Using Wood Waste - East Sullivan |
| 2.32.3b | Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review |
| 2.34.1 | Use of Cementitious Covers to Control Acid Generation at Westmin's HW Mine - Shotcrete Field Trial |
| 2.42.1a | Development of Synthetic Polymers - Laurentian |
| 2.45.1a | Separation of Sulphides from Mill Tailings |
| 3.13.1a | Passive Treatment of Small Seeps |
| 3.21.2a | Removal of Metals from AMD - Chemical Treatment |
| 3.22.1 | Canada-wide Survey of Acid Mine Drainage Characteristics |
| 3.32.1 | Lime Treatment - Process Review and Sludge Stabilization |
| 4.3.2 | Reference Material NNP |
| 4.5.1b | Waste Rock Sampling Manual - Phase II |
| 4.5.3 | B.C. Technical Guide Revision Monitoring Chapter |
| 4.6.1 | Assessment of Geophysical Monitoring Methods |
| 4.6.3 | Review of State-of-the-Art Remote Monitoring Technology |
| 4.6.4 | Piezocone Field Test |

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| 4.8.2 | Sediment Sampling Probe Field Application |
| 5.6.2 | Third International Conference on the Abatement of Acidic Drainage |
| 5.8.1 | Economic Evaluation of MEND-developed Technology |
| 6.1 | New Ideas Solicitation - Round 1 |

***PREDICTION*** ***Modelling***

**Project 1.14.2**: Monitoring & Modelling AMD from Waste Rock: Mine Doyon Phase II
Budget: $450,000
Sponsors: ........................................Cambior $ 75,000
CANMET ........................................$150,000
Québec ........................................$150,000
Lac Minerals ........................................$ 75,000
Expenditures: $450,000
Manager: A. Paquet, CRM
Contractor: Laval University

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**Objectives:**

The objectives for the project were as follows:

- Continue collection of baseline data; physical, chemical and bacteriological field measurements, chemical analyses, and meteorological data initiated in Phase I.
- Develop a waste rock alteration indicator for determining the extent of oxidation.
- Determine the rate of AMD generation and predict long-term behaviour as a function of potential control measures.

**Outputs:**

The south dump at Mine Doyon has afforded an excellent opportunity to study a waste rock dump in detail. Phase I (1.14.1) resulted in the instrumentation and detailed characterization of the south waste rock dump, as well as long-term prediction of acid generation potential using two independent methods. Phase II continues and augmented the monitoring program initiated in Phase I. From the information collected, geochemical, physical and hydrologic simulation capabilities were developed.

Important physical parameters such as climatic data, temperature profiles within the dump, total discharge of acid drainage from collecting ditches and chemical composition of the effluents were monitored on a regular basis. Other parameters were measured once or at regular intervals and included: gas composition, piezometric levels, leachate composition in the unsaturated zone, infiltration rates, particle size and surface temperature. It is the first time that such a coherent and comprehensive set of parameters is assembled in a large waste rock dump.

The data collected were presented in a series of seven topic-specific reports from November 1992 to March 1994 including a summary report completed in June of 1994.

***PREDICTION*** ***Chemical Prediction***

**Project 1.16.2a:** Prediction Test Standard Material: Interlaboratory Program for Characterization of the ARD Standard Material NBM-1

Budget: $20,000

Sponsors: Environment Canada $10,000

CANMET ................................................ $10,000

Manager: H. Steger, CANMET

Contractor: CANMET: Canadian Certified Reference Materials Project (CCRMP)

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**Objective:**

This project was meant to extend the characterization of the standard material, NBM-1, for use as a standard material for acid rock drainage static prediction tests.

**Outputs:**

The material, processed to minus 200 mesh, has been bottled and sealed under nitrogen in foil pouches to protect against oxidation. The homogeneity with respect to iron and sulphur has been confirmed and carbonate concentrations determined. Fourteen laboratories were selected on the basis of their experience with ARD methods and previous participation in other CCRMP projects. Participants were requested to follow the Sobek acid-base-accounting method for the determination of NNP using a specified fizz rating of "slight".

The results showed a bimodel distribution and the mean of the NNP results was assigned provisional status, in that the mean NNP value is not certified. This value, $42 \pm 9$ tonnes $CaCO_3$/1000 tonnes, refers to the determination of NNP by the Sobek method with a fizz rating of slight and is subject to change as further analytical information becomes available. Values were also reported by the participating laboratories for paste pH, fizz test rating and NNP by other methods.

The standard material produced, NBM-1, can be used for the very necessary method development and as a control standard for acid-base-accounting.

The results are detailed in a report completed July 1994.

**Recommendations:**

Additional studies aimed at improving the standard ABA method should be considered. It is also recommended that further work be performed on the standardization of NBM-1 for NNP by other methods. Subsequent standard reference materials should also be prepared.

***PREDICTION*** ***Modelling***

| | | |
|---|---|---|
| **Project 1.22.1**: | Assessment of the ANSTO Gas Transfer Model at Heath Steele, Newcastle, N.B. | |
| Budget: | $145,000 | |
| Sponsors: | CANMET | $87,290 |
| | New Brunswick | $22,710 |
| | Noranda | $35,000 |
| Expenditure: | $145,000 | |
| Manager: | E. Yanful, Noranda | |
| Contractors: | Nolan Davis & Associates<br>Australian Nuclear Science & Technology Organization<br>Noranda Technology Centre | |

**Objectives:**

The objectives of this project were to develop an understanding of the processes governing pyrite oxidation rates in acid waste rock piles at Heath Steele, to quantify those processes, and to evaluate the effectiveness of the composite soil cover for acid waste rock management.

**Outputs:**

The field component consisted of *in situ* measurements of various parameters required by FIDHELM, namely the oxygen diffusion coefficient, air permeability, and thermal conductivity. These parameters were successfully measured and found to be in acceptable ranges when compared to other waste rock piles.

The modelling component consisted of running FIDHELM employing the Heath Steele data collected during the field work. Gas transport mechanisms dominating the oxidation rates were identified using observed temperature and oxygen profiles in conjunction with FIDHELM simulations. A user's manual was also prepared.

Numerical simulations indicate that gas transport is dominated by diffusion. These simulations also suggest that particular details in the oxygen profile measured at Heath Steele can be explained by the heterogeneity of the pile. Modelling of the waste rock pile with the soil cover in conjunction with field data indicate that the soil cover is effective to reduce the ingress of oxygen. Data collected to date agree with these simulations.

**Recommendations:**

A program of work to quantify the effect of advection by wind effects and to compare measured results with modelled results was recommended. Continuous monitoring of temperature and pore gas oxygen concentration profiles throughout the entire year could be considered.

***PREDICTION*** ***Modelling***

| | |
|---|---|
| **Project 1.41.2**: | ARD Waste Rock Monitoring Database |
| Budget: | $22,000 |
| Sponsor: | CANMET |
| | $22,000 |
| Expenditures: | $22,000 |
| Manager: | E. van Huyssteen, CANMET |
| Contractor: | University of British Columbia |

**Objective:**

The objective of the project was to develop a database to provide an overview of all significant ongoing and past field monitoring studies of acid or potentially acid generating waste rock dumps in Canada and internationally.

**Outputs:**

Following a review of available data access systems, a PC Windows[1] based application (Paradox for Windows[1]) was chosen for the database. The database was constructed with five tables to contain information as follows:

- general mine information
- general waste rock dump characterization
- waste rock dump material characterization
- monitoring program details, and
- data access.

Details of the monitoring program include the parameters measured, the methods and instrumentation used, the temporal and spatial extent of measurements, and any data analysis or modelling done as well as a summary of any conclusions drawn.

As part of the gathering of information, a questionnaire was sent to solicit waste rock dump information and sent to over seventy contacts in Canada and internationally. Data was obtained for 31 mines and 45 associated waste dumps from Canada, Australia and Sweden. The data is available in a database format for Paradox for Windows[1], Microsoft Excel[1] spreadsheets and text delimited files.

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***PREDICTION*** ***Basic Research***

**Project 1.51.1**: Quantitative Analyses of Chemical and Biological Kinetics
Budget: $12,000
Sponsor: Environment Canada $11,750
Expenditures: $11,750
Manager: B. Godin, Environment Canada
Contractor: Synergetic Technology

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**Objectives:**

The primary objective of the project was to provide a quantitative analysis of the interrelated elementary chemical and biological processes that together are responsible for pyrite oxidation and acid rock drainage. A secondary objective was to determine whether the coupled chemical reactions involved in the multistage oxidation of pyrite lead to irregular or chaotic, in time, changes of products of the chemical and microbial reactions responsible for acid rock drainage.

**Outputs:**

The final report reviews and critically analyzes several experimental and theoretical results on chemical, physical and biological aspects of pyrite oxidation. In describing interrelated elementary chemical and biological processes associated with ARD, a clear distinction between oxygen requiring and non-oxygen requiring processes is made. The dependence of relative rates of reaction on pH is discussed and several experimental results and rate constants are re-evaluated. Based on available information a kinetic model in the form of coupled non-linear ordinary differential equations were constructed for the coupled chemical reactions responsible for ARD. The model is based on small-scale experimental data for pure pyrite. Computer simulations for the concentrations of $H^+$, $Fe^{2+}$, $Fe^{3+}$, and $SO_4^{2-}$ have been performed for different values of the controlling chemical and physical parameters. The model does not include transport processes. Biological activity associated with pyrite oxidation is considered with respect to temperature, pH, available oxygen and other oxidants. Kinetic equations for biological activity are proposed for the first time. The set of non-linear kinetic equations considered in the study for the chemical reactions involved in pyrite oxidation does not appear to produce chaotic behaviour or other types of chemical oscillations. The report indicates however that the study does not exclude such physico-chemical oscillations when processes of water and oxygen transport are included.

**Recommendations:**

Based on the review done, several areas that may merit further laboratory and modelling studies are identified. The report recommends that the quantitative results presented therein be assessed with field data.

***PREDICTION*** ***Basic Research***

**Project 1.51.2**: Non-linear Modelling of Chemical Kinetics for Acid Mine Drainage

Budget: $30,000

Sponsor: Environment Canada $34,550

Expenditures: $34,550

Manager: B. Godin, Environment Canada

Contractor: University of Alberta

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**Objectives:**

To determine the initial conditions that will lead to chaotic behaviour and other non-linear behaviours and to determine the area of predictability versus non-predictability in ARD chemical evaluations.

**Outputs:**

The reduction of impact from ARD requires accurate prediction. However, the complexity of the chemical reactions involved precludes an easy and simple approach to the problem. The chemical processes are not only strongly dependent on external conditions (weather etc.) and the geology of the terrain but, they also involve feedback loops making the problem inherently non-linear. Accurate prediction must also account for competition between neutralization and acid generation. This project was chiefly concerned with the modelling of non-linear kinetics of the chemical reactions present in both acid production and acid neutralization, that are associated with the ARD process. An extensive literature survey encompassing both geochemical analyses regarding AMD and the relevant aspects of non-linear chemical kinetics was conducted. The report looks at the chemical reactions involved in the chemical oxidation of pyrite (ie. type, activation energy, rate, and thermodynamics). A theoretical mathematical model, rather than empirical, has been used to explore a wide range of extreme situations to uncover non-trivial behaviour. No chaotic behaviour was found in the case of pyrite oxidation. Sulphide chemical oxidation does intrinsically produce variability in results. Therefore based on chemistry alone, it is possible to predict ARD outcomes. Irregular variations in chemical species concentrations are observed and this irregular behaviour seems to be mainly affected by the porosity of the medium and the presence of non-zero flow rates of oxygen and water.

The report indicates that no chemical chaos exists in the pyrite oxidation, but that the effect of physical processes may have a greater effect on the predictability of acid rock drainage problems.

**Recommendations:**

The diffusivity of motion of the chemical species needs to be addressed because of the heterogeneity of the host environment.

## *PREVENTION AND CONTROL -Underwater Disposal*

**Project 2.11.3 abc**: Evaluation of Underwater Disposal Site - Anderson Lake
Budget: $400,000 a: $125,000 b: $275,000 c: $10,000

| | | |
|---|---|---|
| Sponsors: | | HBM&S |
| | | $214,000 |
| | CANMET | $100,000 |
| | Manitoba | $ 90,000 |
| | Environment Canada | $ 6,000 |

Expenditures: $410,000
Contractors: Rescan Environmental/ASL Laboratories
University of British Columbia/Environment Canada (NWRI)

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**Objective:**
The objective of the Anderson Lake program was to address the recommendations made by the peer review and to provide the additional information needed to support the application of the subaqueous disposal method. The focus of the project completed at Anderson was on field and analytical techniques to improve measurement of metal fluxes at the sediment/water interface.

**Outputs:**
Specific comments from the peer review (2.11.1d) focused on the requirements for additional work on Quality Assurance/Quality Control (QA/QC) on all phases of the program from sampling to analysis to yield statistically valid results. Two campaigns were completed at Anderson, late winter 1993 (2.11.3a) and mid-August 1993 (2.11.3b), which included water column sampling, sediment cores, and peepers, as well as measurements of field parameters. Diurnal temperature profiles were obtained, and in-situ recording thermistor strings provided a full data set of water column temperature profiles with changing seasons. Two weather stations were erected for temperature, wind and precipitation data to assist in interpreting the data from the lake and in developing future generic application criteria. A cross-comparison was done on two methods of handling samples from the peepers: under inert atmosphere and sample extraction under normal atmosphere. Results from both campaigns, particularly the high-resolution water column sampling, confirm the findings from earlier studies that the sediments were acting as a sink rather than a source for metals for the water column.

In 1994 an assessment of the mine-related inputs to Anderson Lake was carried out to determine as much as possible the extent of relationship between the various discharges and observed historical changes in lake chemistry. Available evidence suggests that the primary controls on metal and acidity enrichments stem from unbuffered underground mine discharges and acid mine drainage from the waste rock used to construct the road. The final report, which includes the two sampling campaigns and the review of historical data will be available in 1995.

**Recommendation:**
The metallurgical operation using the lake for tailings disposal will be reopened in 1995 and consequently, the post-production campaign has been cancelled. Further work may result from the second peer review (2.11.1e).

***PREVENTION AND CONTROL - Wet Barriers***

**Project 2.13.1**: Flooding of Existing Tailings Sites - Quirke Lake
Budget: $835,000
Sponsors: Rio Algom $502,000
CANMET ............................................$333,000
Expenditures: $835,000
Contractors: Rio Algom Limited/CANMET

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**Objective:**
The objective of this project was to investigate the feasibility of establishing a shallow water cover or wet barrier on pyritic uranium tailings as a close-out option for controlling acid generation and release of metals and radionuclides.

**Outputs:**
During the spring of 1989, Rio Algom and CANMET began a joint project to assess the feasibility of flooding the existing Quirke tailings site as a close-out option. The following was completed:

- various projects on applications of wetlands (e.g. literature review, field evaluations of sites: hydrogeochemical and biological characterization, and survival and propagation studies on tailings;
- column lysimeter tests (oxidation, leaching and neutralization); and
- preparation of a large-scale field demonstration program (65 ha). This included levelling of the tailings surface, limestone addition, liquefaction study, piezometer installation, flow control structure, continued sampling and monitoring during and after flooding.

Flooding of the 65 hectares test site (Cell 14) commenced in November 1992 and monitoring has been ongoing since. The monitoring program has included: detailed monitoring of inflows and precipitation; water level measurements in the pond and piezometers; and water chemistry and surface water quality sampling. The data to date are very positive and compare well with modelling prediction.

Reports from Rio Algom (e.g. geotechnical aspects, design recommendations and construction drawings, hydrogeology, water chemistry) will be available in 1995. The draft reports by CANMET summarizing the laboratory studies are being reviewed by Rio before release through MEND.

**Recommendation:**
Further monitoring of the test cell will be completed by the company and it is expected that the data will be made available to MEND. It is recommended that further work be completed on the effects of secondary mineral solubility and release rates on water quality (2.15.2).

### *PREVENTION AND CONTROL -Wet Barriers*

**Project 2.13.2abc**: Flooding of Existing Tailings Sites - Solbec Cupra
Budget: $260,000
Sponsors: ..................................................................Cambior $ 99,600
Québec .................................................... $ 88,200
CANMET ...............................................$103,100
Expenditures: $291,000
Contractors: Roche Ltée./Université Laval/McGill University

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**Objective:**
The objective of this project was to determine if a water cover prevents the continued oxidation of acidic tailings containing about 30 to 50% sulphide.

**Outputs:**
The first phase of the project (1989 - 1990) involved the installation of instrumented experimental basins with a one-metre water cover and watertight sides. Results confirmed that a water cover prevents the oxidation of fresh tailings. However, porewater samples taken in the oxidized tailings are acidic, even after flooding. In 1991 a hydrogeological study of the tailings basin confirmed that flooding of the tailings is possible with natural precipitation and surface runoff over an eighteen-month period. Construction of impervious dams and/or levelling of the tailings surface at the south end was required to maintain a one-metre water cover. The 1992 - 1993 program involved the installation of a new basin to determine the effect of adding neutralization to the oxidized layer prior to flooding.

The key conclusions from the synopsis report that evaluated the collected data since 1989 are that: flooding under a shallow water cover inhibits further oxidation of acidic tailings and prevents the process in non-oxidized tailings; the inhibitive effect is progressive, and porewater in oxidized tailings remains acidic for a certain time before reaching a neutral level; and, neutralization of the oxidized layer by adding and mixing finely crushed limestone prior to flooding has the effect of rapidly stopping the oxidation process and raising and maintaining porewater pH to neutral levels. In a second project the minimum depth of water required to prevent resuspension of solid particles through wind action was found to be 1.34 m. However, with a layer of sand on top of the tailings the required level may be reduced to 0.7 m. In another related study on the microbiological factors it was found that there was no bacterial activity in the 1989 flooded lysimeters. However, a large bacterial population was found outside the experimental basins in the oxidized tailings. The three reports, 2.13.2a, 2.13.2b and 2.13.2c are available from CANMET.

**Recommendation:**
Cambior started on flooding the site in late 1994. MEND recommends that a field monitoring program be implemented during and after flooding (2.13.2d).

### *PREVENTION AND CONTROL -Wet Barriers*

**Project 2.13.3**: Flooding of Existing Tailings Sites - Falconbridge
Budget: $170,000
Sponsors: ................................................................ Falconbridge
$ 155,000
Ontario ................................................ $ 15,000
Expenditures: $170,000
Contractor: University of Waterloo

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**Objective:**
The primary objective was to establish the suitability and effectiveness of a water cover on top of sulphitic tailings to prevent acid generation and metal mobilization through site assessment and development of a hydrogeochemical model.

**Outputs:**
Studies have been conducted on Falconbridge's 90 hectare "New Tailings" site to evaluate the feasibility and control provided by a shallow water cover on high sulphur (40 to 50%) pyrrhotite tailings. The tailings are underlain by low permeability silt and clay deposits, and are partially covered with low sulphur (1%S), low permeability tailings slimes (0.3 to 2 metres in thickness) to decrease the oxygen and water movement through the tailings prior to flooding. The slime cover has raised the phreatic surface within the tailings, and consequently most of the high sulphide portion is saturated and presently in the unoxidized state. After three years of abandonment, without a water cover, the tailings area has not turned acid.

To date the hydrogeochemistry of the entire site has been extensively evaluated . The water chemistry in the tailings and the gas compositions in the vadose zone indicate that oxidation of pyrrhotite in the tailings is ongoing. A second component of this project was the development of a computer model (WATAIL) to assist mining companies in the management of water quality associated with disposal of sulphide tailings. The objective of the program is to provide comparisons in loading rates of the major oxidation products to surface water draining from the local watershed in which the tailings basin is contained. The program focuses on rehabilitation strategies based on engineered covers, including underwater scenarios.

The economic benefits of flooding the entire site were predicted to be less beneficial because of the stored oxidation product in the tailings that would result in long term treatment. With this in mind, Falconbridge is investigating the possibility of using municipal solid waste compost and/or other organic materials as covers for the higher elevated areas (Project 2.25.3) and flooding of the low lying areas.

**Recommendation:**
No further work is planned for the "New Tailings" site until the completion of the organic covers project (2.25.3).

***PREVENTION AND CONTROL -Dry Barriers***

**Project 2.20.1**: Evaluation of Alternate Dry Covers for the Prevention of Acid Mine Drainage from Tailings
Budget: $50,000
Sponsors: Lac Minerals $ 5,000
Ontario ........................................ $25,000
CANMET ........................................ $25,000
Expenditures: $55,000
Contractor: SENES Consultants Limited

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**Objectives:**
The objectives of the study were to prepare a ranking of the potential alternate cover materials (e.g. desulphurized tailings, tailings slimes, modified soils and wood waste) that could be considered for further dry covers research. The project would document potential alternatives from literature sources and personal contacts, outline possible means of application and the pro's and con's of each. The alternates would be ranked according to potential for success and relative cost.

**Outputs:**
One of the primary methods of preventing acid mine drainage from tailings is the placement of a cover which reduces the amount of oxygen and/or water that contacts the acid-generating sulphides. The theoretical concept of dry covers was reviewed and the barriers classified as oxygen barriers (moisture retaining), oxygen consuming, or reaction inhibiting. Potential barrier materials were identified through a technical literature search; a literature review focused on forest product industry wastes, and a search for potential materials that may be obtained from municipal and industrial wastes. A short list of potential materials was developed applying a two-stage screening process which took technical aspects, cost, and practical application into consideration. Potential barrier materials considered to provide broadly based (country wide) benefit and a good likelihood for success are listed. Recommendations are made regarding the future direction of dry barriers research and specific research work currently underway.

Potential materials given a high priority for future research include natural soils, modified soils, desulphurized tailings, tailings slimes, wood waste, and paper mill sludge. Materials given a lower priority for future research include peat, waxes, ashes, and phosphate. Available barrier materials not requiring additional research are limestone (mixed into the tailings mass), and synthetic liners. The final report is available from CANMET.

**Recommendation:**
There is a need for the development of affordable dry barriers technology and future research should be directed on priority materials. It is recognized that the main emphasis for dry barriers research is that the results must have significant cost-saving potential over existing technology.

***PREVENTION AND CONTROL - Others***

**Project 2.23.2d:** Geochemical Evaluation of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines
Budget: $250,000
Sponsors: ........................................................ Falconbridge $140,000
Ontario ........................................................ $ 60,000
CANMET ........................................................ $ 60,000
Expenditures: $260,000
Contractors: University of Waterloo/CANMET

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**Objectives:**

The objectives were to characterize the hydrogeological flow system, the geochemical interactions between the porewater, pore gas and solids and to determine the influence of discharging tailings porewater on the quality of run off from the tailings during storm events. The results of the research could then be used to aid in predicting the future effluent quality.

**Outputs:**
Tailings disposal by the thickened, sloped, discharge method has been shown to provide a homogeneous tailings mixture with high moisture retention and low hydraulic conductivities which aid in the abatement of acid generation.

The elevated central area of the cone is a groundwater recharge area where precipitation infiltrates and moves downward to replace porewater that flows away from this area. Recharge rates vary from a maximum near the apex of the cone and decline outward toward the perimeter. The dominant porewater flow is radially outward from the centre of the impoundment to discharge in the flat-lying peripheral areas.

Four distinct geochemical zones were identified in the cone. The bottom layer has high alkalinity and low dissolved metals. The next layer also has high alkalinity and the water found in the tailings has the properties of mill water. The following layer is the jarosite affected zone. The current practice of co-disposing jarosite with sulphide-rich tailings introduces the jarosite to a neutral-pH and low $E_H$ environment in which it is thermodynamically unstable. It has been found only about 10% of the neutralization capacity would be consumed by the jarosite which is equivalent to about 1% of the carbonates contained in the jarosite affected zone. The only sign of sulphide oxidation is found in the top layer. The products of sulphide oxidation reactions will move through the tailings with the porewater. The hydraulic conductivity in the cone has been reported to be quite low ($10^{8}$ m/s). The geochemical - hydrogeological, and hydrological studies are confirming that the TTD method has benefits in terms of controlling acidic drainage.

**Recommendations:**
At the completion of the tracer study (2.23.2c), it is recommended that a synopsis report assessing the effectiveness of the TTD option be completed.

***PREVENTION AND CONTROL - Others***

**Project 2.23.3**: Porous Envelope Surround Disposal Method - Falconbridge
Budget: $190,000
Sponsors: ........................................................ Falconbridge $116,000
Ontario ........................................................ $ 76,000
CANMET ........................................................ $ 15,000
Expenditures: $207,000

Contractors: Noranda Technology Centre/Geomar Geophysics Ltd.

**Objectives:**
The objectives of the investigation were to analyze the chemical and physical hydrogeology of the site, to delineate areas affected by acid mine drainage (AMD) generated from the tailings, and to verify the presence of the porous envelope effect.

**Outputs:**
Field activities and computer flow modelling conducted over the past three years concluded that conditions for porous envelope containment are occurring at the Falconbridge Fault Lake tailings site. Water quality sampling did not show any evidence of above background metal concentrations, which suggests minimal leaching of metals from the tailings. Flow modelling supported the porous envelope hypothesis, which corroborates the inference that impact to the regional groundwater by tailings oxidation is insignificant.

The glacial sediments surrounding the Fault Lake tailings site are characterized by their elongated formation and relatively high bulk hydraulic conductivities. This creates a flow system with a relatively flat and deep water table. Factors which contribute to limit metal concentrations down gradient of the Fault Lake tailings are: 1) high hydraulic conductivity contrast between the tailings and the surrounding sediments, 2) low position of the water table relative to the tailings bottom, 3) limited infiltration through the surface of the tailings, 4) dilution of metals flushed from the tailings by water flowing around and below the tailings, 5) chemical attenuation of metals in the tailings and overburden.

All five factors outlined above contribute to create the porous envelope effect; these factors could probably be present at other locations near mine sites. Tailings deposition in these types of environments could be done with little effect on groundwater quality, if thorough site evaluations are performed and appropriate control is enforced at the time of deposition. The draft report was received in late-December and is currently under review. The final report should be available in 1995.

**Recommendation:**
The report shows that the porous surround method has long term merits for the control of acidic drainage. As a closure report for this disposal method, it is suggested that a review of basic principles and design parameters to obtain the porous effect, for both engineered (Rabbit Lake) and natural (Fault Lake) systems, be completed.

### *PREVENTION AND CONTROL -Dry Barriers*

**Project 2.25.1:** Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost

| | |
|---|---|
| Budget: | $130,000 |
| Sponsors: | Falconbridge $53,500 |
| | Ontario $32,500 |
| Expenditures: | $ 86,000 |
| Manager: | M. Wiseman, Falconbridge |
| Contractors: | Laurentian University/Falconbridge |

**Objective:**

The objective of this study was to conduct a laboratory investigation to determine the optimal cover design and safety of using municipal solid waste compost as a permanent solution cover in an abandonment strategy for mine tailings. The results of the study will assist in the design of pilot or field studies of compost cover layers.

**Outputs:**

Phase I was to conduct a literature review of what is known about the physical and chemical characteristics of municipal solid waste (MSW) compost and other organic materials (Project 2.25.1a). The conclusions of the survey led to this laboratory research project, started in 1992. The experimental work has shown that a cover layer of MSW compost can be of benefit in the reclamation of oxidized tailings. There is strong evidence of a reversal of AMD processes in the oxidized tailings as shown by the formation of iron sulphide precipitate (note: fresh compost was more effective in the short term than mature compost) near the cover layer - tailings interface. The mobilities and distribution of trace metals indicate that significant reductive dissolution of tailings oxides was still in progress in the tailings layer at the end of a nine month simulation. Trace metals became less mobilized with the development of reducing conditions and tailings pH increased to as high as 8. Compost quality tests show that leachates from mature and fresh compost present a low environmental risk for use on mine lands. The final report will be available from CANMET in 1995.

**Recommendations:**

The conclusions were based on a relatively short term laboratory experiment and this study should be seen as a preliminary look at compost cover layers and their design as a tailings AMD solution. Comprehensive, long term laboratory pilot scale work should now be done (Project 2.25.3) to follow up on the potential benefits that were identified for organic type materials. An economic evaluation, recognizing the practical and regulatory conditions in Ontario, suggests that utilizing organic type materials for covers has both practical and economic justification for both the mining industry and municipalities.

## *PREVENTION AND CONTROL -Dry Barriers*

**Project 2.25.2**: Design of an Organic Barrier Using Wood Waste - East Sullivan
Budget: $431,000
Sponsor: ........................................................................Québec $210,000
Expenditures: $210,000
Contractors: Roche Environmental Ltd./Centre de recherches minérales

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**Objective:**
The objective of this study was to evaluate the effect of wood waste covers on the process of tailings acidification and the effect of organic amendments on the quality of the surface and groundwater at the East Sullivan tailings site in northwestern Québec.

**Outputs:**
MEND is evaluating a number of organic covers which are classified as oxygen consuming layers. It is perceived that the organic materials will create a strongly reducing layer due to the continued biological degradation of the organics. These covers may require the intermittent addition of new organic material to maintain the oxygen scavenging capability. Covers made of forest waste or other organic wastes will be useful for the mining industry only if they provide a permanent, socially-acceptable and cost-effective method of tailings cover.

A preliminary field test, on a 10 m X 10 m test plot in old wood waste at East Sullivan, was completed in 1991. The results demonstrated that a one-metre wood waste cover effectively blocks access of oxygen which could oxidize underlying sulphates, as shown by the fact that methane is generated.

In 1992 six 20 m X 20 m experimental test plots, with monitoring instrumentation, were constructed on the site. Sampling campaigns of the solids (e.g. wood waste), gas and liquid phases were carried out over a three year period. The analysis of interstitial gases in a layer of wood chips 100 cm thick covering mine tailings demonstrated that this material effectively blocks access to oxygen which could oxidize underlying sulphates, as demonstrated by the presence of methane. Monitoring results on the gas concentrations in the wood wastes have shown that the oxygen concentration dropped from 16.1% to less than 1.5% at a depth of 70 cm and $CO_2$ levels increased from 8.2% to 50.8%. Concerns about spontaneous combustion in the cover material were noted because of the high concentrations of methane gas at depth ($\approx$ 90 cm) and possible formation of methane gas pockets. The high permeability of the material and the 1 metre thickness of the cover should prevent methane pockets and spontaneous combustion. High concentrations were found in the test cell containing sewage sludge which probably filled the voids and prevented the methane from escaping.

**Recommendation:**
The study suggests that additional monitoring for gas and oxygen be carried out. The reductive covers projects (2.25.3) will also be reviewing more generic type research on organic materials for covers.

## *PREVENTION AND CONTROL -Waste Rock*

**Project 2.32.3b**: Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review
Budget: $10,000
Sponsor: ........................................................................Québec $10,000
Expenditures: $9,990
Contractor: Université Laval

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**Objective:**

The objective of this project was to evaluate the feasibility of injecting mine tailings into a waste rock pile as a method to control acid mine drainage.

**Outputs:**

The prime function of injecting tailings into a waste rock pile is to reduce porosity and permeability and increase the degree of saturation of the pile. The result will be a major reduction of air entering the waste rock pile thus eliminating convection, if present and consequently reducing the reactions causing acidic drainage. It also has the advantage of using a waste product.

The literature review revealed that the injection concept is a unique method that has not been tried before. The review centred on possible analogous research that could be applied (e.g. hydraulic backfill, flow transport modelling, cementing additives, physical parameters, etc..) to develop the injection process.

Based on these findings a laboratory program was developed and proposed. To achieve the various objectives of the laboratory program, various tests will be required. They have been grouped in five areas: identification tests (characterization of the samples from the various sites); rheological measurements (e.g. viscosity); injection tests in one dimensional columns and three dimensional reservoirs; dynamic tests (e.g. void ratios, liquefaction); and chemical analyses. Field injection pilot tests were proposed in the third year and these would be based on the laboratory results. A cost benefit analysis would also be completed after the two-year laboratory study. The proposed budget for Phase II is $375k. The final report for Phase I will be available from CANMET in 1995.

**Recommendation:**

Following a review of the Phase I report: Literature Review and Proposed Work Plan for Phase II, the committee recommended that a $100k proof of concept study be undertaken by the proponent to complete a technical and economic feasibility study of the injection process. The requested amended proposal was never submitted to MEND and no further work is planned.

***PREVENTION AND CONTROL -Waste Rock***

**Project 2.34.1** Use of Cementitious Covers to Control Acid Generation at Westmin's HW Mine - Shotcrete Field Trial
Budget: $130,000
Sponsors: ........................................................................ Westmin
$100,000
CANMET ............................................. $ 30,000
Expenditures: $130,000
Contractors: Northwest Geochem/Powertech Labs

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**Objectives:**
The objectives of this study were to apply a cementitious cover in the most effective manner and to evaluate the material properties and the long term efficacy of the cover system. In addition, the test provides an opportunity to develop better automated techniques for large-scale application of the shotcrete cover material.

**Outputs:**
Approximately 3500 square metres of waste rock was covered using the shotcrete process in August 1992 at Westmin's Myra Falls site near Campbell River, B.C. A robotic arm mounted onto a vehicle was used to apply the shotcrete. The cementitious material used in the project incorporated high volumes of fly ash (a waste product) to reduce the material cost. The shotcrete mix also included the use of polypropylene fibres to control cracks. The test area was instrumented with survey markers to monitor settlement in the rock slope.

The performance of the test area has been monitored to evaluate the durability of the cover when subjected to field conditions. Compressive strength increased in the first year and all samples achieved or exceeded the design criteria. Some hairline cracks, superficial only, formed during the curing period but have not expanded after enduring two winters. Other cracks have penetrated through the cover and work is progressing to see how much moisture has reached the waste rock. No new cracks have been found as a result of the freeze/thaw cycles. The study indicates that shotcrete dry covers can be a viable option for sealing prepared waste rock piles. The final monitoring report is due in 1995.

A major consideration in the design of the test program was cost. The transportation of aggregate to the mine site was the largest cost. If a local aggregate source, such as coarse tailings, was available the unit cost per square metre of cover could be less than twelve dollars (from an estimate of $18.46); a saving of approximately 30 percent.

**Recommendation:**

The study did not evaluate the effectiveness of the cover in restricting acid generation. To evaluate the effectiveness to control acid generation, it was recommended that this cover technology be applied in a controlled field trial on a designed isolated waste rock pile.

***PREVENTION AND CONTROL - Others***

**Project 2.42.1a**: Development of Synthetic Polymers - Laurentian
Budget: $83,000 a: $45,000
Sponsors: .......................................................................... INCO
$22,500
Ontario .................................................. $22,500
Expenditures: $45,000
Contractor: Laurentian University

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**Objective:**

The project objective was to synthesize a polymeric material(s) with specific engineering characteristics. The ideal material(s) would have the following properties, in tailings ponds, it would: a) be water soluble; b) provide long term bactericidal action; c) strongly adsorb onto particulate matter; d) flocculate fines when wet; e) act as a binding agent for fines when dry; and f) complex any previously leached metals. In waste rock it would also: g) be readily foamed to allow penetration into the pile; and h) have virtually no oxygen permeability.

**Outputs:**

A number of approaches were tried in synthesizing various components of the required polymer(s). As anticipated, most were not effective and efforts were focused on those showing significant results.

Work on heavy metal chelating polymers was focused on the development of a synthetic route that would produce 100% polyvinyl amine (XPVAm) in good yield. This polymer is reacted with chloroacetic acid to obtain a structural feature that approximates an EDTA structure. Synthesis of bactericidal polymer was also started and partially worked out.

Due to the death of the principal researcher, Phase (a) was not completed. Two reports, prepared by graduate students at Laurentian, are under review. A decision will follow on whether the information is adequate for submitting to MEND as a final report for Phase (a). If yes, a final report summarizing the data from both graduate student reports will be prepared and submitted.

**Recommendation:**

MEND recommends cancellation of Phase (b) and, the project totally removed from MEND if no acceptable report is submitted for Phase (a).

## *PREVENTION AND CONTROL - Others*

**Project 2.45.1a**: Separation of Sulphides from Mill Tailings
Budget: $75,000
Sponsors:

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|---|---|
| CANMET | $20,000 |
| Ontario | $20,000 |
| Lac Minerals | $15,000 |
| Placer Dome | $10,000 |
| Les Mines Selbaie | $10,000 |

Expenditures: $75,000
Contractor: Cominco Engineering Services Ltd.

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**Objectives:**
The objectives of this project were to evaluate various mineral processing techniques that could be applied to the separation of sulphides in tailings, to evaluate the relationship between sulphide elimination and acid generation, and to evaluate the operating costs of various separation options.

**Outputs:**
A review of various mineral processing separation techniques and their application for the removal of sulphides from mill tailings was completed. The project included a descriptive review of the operating principles of each technology as well as bench scale testing of several processing methods.

Four mill tailings samples were obtained from three operating mines. These were characterized to determine their acid generating potential. The samples were processed by gravity and flotation separation processes to split the samples into sulphide and non-sulphide fractions. The separation processes tested included: Falcon Concentrator; Knelson Concentrator; Reichert Tray, 1/8 Wilfley Table; Carpco LC 3000 Spiral Concentrator; and direct flotation (variety of preprocessing steps and collectors). The samples were then reanalysed to determine the effectiveness of the sulphide separation. The characterizations included humidity cell tests and acid base accounting, ICP analysis and a mineralogical evaluation. Conceptual flow sheets were developed for each sample and the cost of implementation estimated.

The results of the study proved that the gravity techniques tested were incapable of separating the sulphides sufficiently to remove the acid generating capability of the tailings. This is likely due to the fact that the sulphide fractions tend to be concentrated in the finest size fractions of the tailings. The separation technique tested that was successful in removing most of the acid generating potential of the tailings samples was direct flotation. The final report is available from CANMET.

**Recommendation:**

The results of this study confirm that flotation is the best method for separation. It is recommended that a project on possible applications of the separated materials (e.g. use in dry barriers) be considered. A MEND Associate project on the use of depyritized tailings as a cover is underway in Sudbury.

## *TREATMENT*

**Project 3.13.1a**: Passive Treatment of Small Seeps
Budget: ($90,000)
Sponsors: .................................................................Noranda
($60,000)
CANMET ........................................... ($30,000)
Expenditures: ($90,000)
Contractor: Noranda Technology Centre

**Objective:**
To evaluate and demonstrate the applicability of various passive, low-cost processes for treating small volumes of acidic seepage.

**Outputs:**
Passive treatment processes are under development and being applied in Canada and the United States and these include anoxic limestone trenches, lime organic beds, biotrenches, and biosorbents. Bench-scale treatment tests were carried out at Noranda Technology Centre in 1992 to evaluate 4 passive treatment methods. Process parameters such as pH, acidity, Eh, metal & sulphate concentrations, flow rates and hydraulic characteristics were determined.

The results suggest that the best system for pH increase and metals removal can be obtained by using combinations of lime-organic mixtures and anoxic limestone trenches, and biosorbents and limestone systems. The final report was completed in early 1994.

**Recommendations:**
Although the completed work has shown some positive results, technical barriers would have to be overcome before applying the methods in the field at Canadian metal mines. Further work would be necessary in some areas, including an economic evaluation of methods, investigation of metal removing processes (including iron and aluminum) and the performance at low temperatures (0-4°C). For these reasons, the Treatment committee recommended not to proceed with a field test. However, these questions were difficult to address in further bench tests due to the time required to assess the effects and different and varying conditions encountered in the laboratory and the field. In the review of passive systems for treatment of AMD, (project 3.41.1) the questions of applicability of these systems in Canada will be addressed.

TREATMENT

*Note: The final report of this project was subject to an extensive review by the Treatment technical committee, and was found to be lacking in several aspects. The Treatment committee recommended, and the Management committee approved that this project be removed from the MEND program and be listed as a Associate MEND project. The final report is available from the MEND Secretariat as an Open File report.*

## TREATMENT

**Project 3.21.2a**: Removal of Metals from AMD - Chemical Treatment

Budget: $100,000
Sponsor: .................................................................... Noranda
.................................................................... $90,000
Expenditures: $90,000
Contractor: McGill University
Noranda Technology Centre

**Objectives:**
To develop and evaluate selective precipitation techniques for separation of toxic metals from typical acid mine drainage.

**Outputs:**
Several chemical methods were evaluated to selectively precipitate and recover metal ions from AMD. A conceptual flowsheet consisting of a three-step precipitation process was developed. The process consisted of oxidizing ferrous to ferric ion with $H_2O_2$ and precipitating ferric hydroxide sludge in the first step, recovering/recycling Zn and Cu as sulphide precipitates in the second step and, in the third step, removing residual metal ions remaining in the water via lime neutralization to obtain a final water quality in compliance with the regulated standards.

Further bench scale investigations were carried out to optimize the initial flowsheet of separating iron as the hydroxide using lime and a dodecylamine surfactant, DDA, which could reduce coprecipitation of other metal ions. Copper and zinc were removed as the sulphide, and techniques were tried to produce a precipitate that could be recycled to a zinc production circuit (smelter - refinery).

The results show that more than 90% zinc recovery and greater that 50% Zn grade can be obtained with the three-step method. A preliminary economic analysis was conducted to compare the various options in terms of available reagents for precipitation and methods of oxidation. Based on the preliminary economic analysis, the feasibility of the proposed value recovery process would be dependent on the costs associated with chemical reagents and solid/liquid separation. The final report is in the editorial process and will be available in early 1995.

**Recommendations:**

Although this study shows positive chemical results, the proposed approach poses economical and technical constraints preventing its further development unless there are new concepts which will radically reduce costs of chemical reagents and solid/liquid separation steps. For this reason, the MEND treatment committee recommended that a proposed pilot test of this process be cancelled and that the financial resources be applied elsewhere.

## *TREATMENT*

**Project 3.22.1**: Canada-wide Survey of Acid Mine Drainage Characteristics
Budget: $15,000
Sponsor: .................................................................... Ontario $15,000
Expenditures: $15,000
Manager: T. Hynes, CANMET
Contractor: CANMET

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**Objective:**
The prime objective was to create a data bank on the composition, flowrates and seasonal fluctuation of acid mine drainage streams in Canada. This information would be made widely available and can be used to define strategies in improving acidic drainage treatment techniques.

**Outputs:**
Fourteen companies participating in the MEND program were contacted by phone and in writing with to respect water quality at their currently acid generating sites. Data on the raw AMD streams at these sites were solicited using a written questionnaire. Detailed information on 72 untreated AMD streams from across Canada was compiled and is presented in the final report. The data were also assembled into a Lotus 1-2-3 spreadsheet designed to allow further analyses of the stream parameters based on selected criteria. The data on stream sources, flowrates, heavy metal concentrations, acidity, oxidizing conditions and suspended solids content have been extracted from the spreadsheet and are presented in a concise tabular format to allow seasonal comparisons. Graphical concentration distributions are provided for several of these parameters.

Seasonal trends in flows and metal contents were observed for many of the stream characteristics. As expected, flowrates are almost always higher in the spring and fall compared to summer and winter. Not many data were available on oxidizing conditions in AMD streams (e.g., $Fe^{2+}/Fe^{3+}$ ratios, or redox potentials).

Information on problems and successes in dealing with AMD at the various sites was extracted from the questionnaire responses and was summarized in terms of generic issues. The two most common concerns/accomplishments involve the collection of all contaminated flows at a site and the quality of the final effluent.

**Recommendation:**

## *TREATMENT*

This report, along with the associated computer spreadsheet, provides a good data bank of Canadian AMD stream characteristics which may be used to assist in developing new or improved AMD treatment techniques. As well, it will allow the formulation of synthetic AMD solutions, which are relevant to the Canadian context, for use in general AMD research. No additional surveys are required under the MEND program.

*TREATMENT*

**Project 3.32.1**: Lime Treatment - Process Review and Sludge Stabilization
Budget: $60,000
Sponsor: ................................................................ Ontario $30,000
CANMET ............................................... $30,000
Expenditures: $60,000
Manager: K. Mailhiot, CANMET
Contractor: SENES Consultants

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**Objectives:**
The state-of-the-art for chemical treatment of all types of acidic drainage encountered in Canada was to be summarized and a reference manual for owners and operators of plants treating acidic drainage from mine sites would be prepared. Recommendations on conducting targeted research and development of lime and other alkali chemical treatment systems would be made.

**Outputs:**
Because long-term treatment of acid mine drainage is in essence the main component of the long term liability at many inactive mine sites, lime treatment and sludge stabilization is a high priority area of work for MEND.

During the two first phases of this project, contacts were initiated with suppliers, researchers, and the mining industry and an information base was developed regarding current and planned AMD chemical treatment practices. Chemical treatment of AMD, at almost all treatment facilities, is based on the use of lime neutralization and subsequent sludge precipitation. Cooperation received from industrial contacts was excellent.

A review of technical databases was undertaken. The information received was reviewed, and standardized summaries were prepared for selected documents. Considerable technical information was available on lime treatment but scientific evaluations of sludge characteristics and disposal were found to be limited.

The final step was to review and assess the current state-of-the-art of AMD treatment technology and sludge management practices to identify gaps. The final report was issued in June, 1994 and workshops based on this report were held in Val d'Or in 1994 and Vancouver in February, 1995. Further workshops are planned for 1995.

*TREATMENT*

**Recommendations:**
Considerable expertise and experience exists on the treatment of AMD with lime. Recommendations on research to fill the identified technology gaps were given. Further work on enhancing the stability of lime treatment sludges was indicated needed.

## *MONITORING*

**Project 4.3.2**: Reference Material NNP
Budget: $28,000
Sponsors: Environment Canada $26,000
CANMET ................................................$ 1,300
Expenditures: $27,300
Managers: B. Godin, Environment Canada/M. Blanchette, CANMET
Contractor: CANMET

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**Objective:**

The purpose of this project was to develop a standard reference material to be used in the prediction testing of the susceptibility of mine waste to develop acidic drainage.

**Outputs:**

A standard material will enable the reliable comparison of results obtained internally and by different laboratories evaluating the acid generating potential of rock samples. No commercially available materials currently exist for this purpose. As a first step, approximately 300 kg of processed standard material for ARD static testing was generated. Formal analysis of the material to obtain standard values for Net Neutralization Potential (NNP), total sulphur and sulphate were conducted in 1994 under the Prediction committee through an interlaboratory test program (1.16.2). Approximately 500 kg of non-ore grade biotite altered biotite feldspar porphyry material from the Noranda Bell Mine in British Columbia was processed to 80% minus 200 mesh by crushing, and grinding and screening. The processed material was blended to ensure homogeneity, bottled under nitrogen in 3429, 100 gram units and the glass bottles sealed in foil pouches, again under nitrogen, to eliminate any further oxidation of the sulphides. Grab samples of the material were analyzed for total sulphur, sulphate, and neutralizing potential to obtain a preliminary value of the material's net neutralizing potential (NNP). From preliminary results the material appears to be an acid consumer, containing 0.36% sulphur and having an NNP of approximately +40 kg $CaCO_3$/t. Characterization of magnesium and calcium carbonate as well as homogeneity testing (iron, sulphur) of the bottled material was completed. The material, NBM-1, will be made commercially available through the CCRMP and is also expected to be used to develop protocols for static prediction test through the MEND program (1.16.2).

*MONITORING*

**Project 4.5.1b**: Waste Rock Sampling Manual - Phase II
Budget: $55,000
Sponsors: ........................................................................INCO
$25,000
Homestake............................................... $10,000
Environment Canada.................................. $10,000
AECB ..................................................... $10,000
Expenditures: $55,000
Manager: M. Blanchette, CANMET
Contractor: SENES

**Objective:**
To provide guidance to the mining industry, consultants and regulatory personnel as to: the type of data required to identify whether a problem exists; the type of testing and analytical procedures available to obtain this data; and the procedures that should be followed to ensure appropriate solutions could be identified.

**Outputs:**
A handbook was produced that provides a concise summary of currently available sampling techniques. The handbook is broken down into 3 main chapters, each dealing with specific areas of waste rock sampling. Chapter 2 addresses representative sampling, sampling program design, data management and quality assurance and control. In Chapter 3, waste rock sampling is categorized and discussed in a common format which includes possible methods, objectives, background, rating, limitations and advantages, recommended procedures, requirements, cost, and references. The final chapter, 4, contains a summary of recommended techniques for obtaining information for rough cost estimates for decision making processes, predictive modelling of potential ARD and the identification of additional sample locations, sample types that may provide valuable secondary information for decision making. This handbook was produced following a detailed survey of waste rock sampling practices currently being applied at sites across North America, Australia and Europe. An experts' workshop was held in Toronto, March 11-12, 1994 following this review. The final handbook was a product of a comprehensive literature review, detailed industrial survey and the experts' workshop.

**Recommendations:**
This handbook is meant to be a guide only and users are cautioned that sampling strategies for waste rock piles will depend upon numerous factors that are site

specific. Mathematical formulations applied to determine the number of samples required from a waste rock pile should be used with caution. Each distinct zone of a waste rock pile should be assessed separately and sample composites should be avoided.

*MONITORING*

**Project 4.5.3**: B.C. Technical Guide Revision Monitoring Chapter
Budget: $53,700
Sponsors: Environment Canada $3,700
CANMET ........................................... $50,000
Expenditures: $53,700
Manager: E. van Huyssteen, CANMET
Contractor: EVS

**Objective:**
The objective of the project is to produce a monitoring manual and a complete revision of the monitoring chapter of the B.C. Draft Acid Rock Drainage Technical Guide.

**Outputs:**
The B.C. Draft Acid Rock Drainage Technical Guide was completed in 1989. Since that time various literature reviews and monitoring projects have been sponsored to address deficiencies identified in the guide monitoring chapter. The first output of this project will be a monitoring guide to include the following: principles, concepts and restrictions in developing monitoring programs; monitoring technology and equipment installation and maintenance; data management, including QA/QC; and advantages and limitations of the techniques as they are applied to various mining and downstream environments. A draft final report has been submitted, reviewed in detail and revised. The report describes the principles, concepts and limitations of developing a monitoring program. A description of the ARD process, including the mine components involved, is given. Sampling techniques and parameters used to monitor ARD sources, pathways and impact are addressed. General guidelines for data management and the development of a working program are presented. The conceptual structure for developing an ARD monitoring manual has been divided into 12 steps. These steps include such areas as: initial characterization; establishment of monitoring needs; development of objectives; where, when, and what to monitor; sample number; monitoring techniques; cost benefit analysis; and data analysis and follow-up. These 12 steps are reflected in the structure of the manual. A glossary of terms and fact sheets for specific parameter assessments (such as salinity, dissolved oxygen, sulphate, etc.) are attached as appendices.

### *MONITORING*

Although the final report contains all essential information as detailed by the contract, it is not concise and is difficult to follow. Thus, it is considered unacceptable by the Monitoring Committee.

**Recommendations:**
A manual of this kind is considered valuable and it was recommended by the Management Committee to re-examine its completion. As a result a new project is proposed to address this.

*MONITORING*

**Project 4.6.1**: Assessment of Geophysical Monitoring Methods
Budget: $118,000
Sponsors: .................................................................... Ontario
$38,000
CANMET ................................................ $38,000
INCO ....................................................... $54,600
Expenditures: $130,600
Manager: E. Cession, INCO
Contractor: INCO Exploration & Environmental Control

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**Objective:**

To demonstrate and document the application of four geophysical methods to detect and assess subsurface migration of acid mine drainage.

**Outputs:**

This investigation focused on electrical and electromagnetic geophysical applications since these methods have the potential to directly detect and map sulphides, areas of active chemical oxidation, and acidic seepage. The research was carried out at two sites in the Sudbury area. Due to the low background conductivities and the high conductivities of AMD, the electrical and electromagnetic geophysical methods were able to detect even small amounts of AMD in groundwater in first time surveys. The work carried out suggests that similar AMD plumes should be detectable at least near their source in most Canadian environments. The geophysical data were correlated with hydrological and chemical data from ongoing groundwater investigations to establish the utility of the methods. The results confirmed that electromagnetic (EM) methods that remotely measure the conductivity of the subsurface are very useful for location and detailed three- dimensional mapping of AMD in groundwater. Airborne surveys can provide rapid reconnaissance scale surveys, while ground surveys and borehole surveys provide progressively more detail. In addition to the EM work, combined induced polarization (IP) and electrical conductivity surveys were tested on a large revegetated tailings area. The IP method detected disseminated sulphides as expected, and the combination of IP and conductivity surveys can be used for simultaneous three-dimensional mapping of sulphides and groundwater quality in tailings. United self potential (SP) surveying showed strong SP anomalies over the tailings. A general recommended sequence for the use of electrical or EM methods in AMD site investigations is outlined in the report.

**Recommendation:**

*MONITORING*

Studies should be integrated using geological, geotechnical, hydrological, geochemical and geophysical methods and data as appropriate. Data from the various disciplines should be entered and maintained in spatially linked databases.

*MONITORING*

**Project 4.6.3**: Review of State-of-the-Art Remote Monitoring Technology
Budget: $60,000
Sponsors: ........................................................................ Ontario
$30,000
CANMET ............................................... $30,000
Expenditures: $58,290
Manager: M. Blanchette, CANMET
Contractor: Patterson, Grant and Watson

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**Objectives:**

The primary objective was the production of a compendium of remote monitoring technologies that identifies and comprehensively evaluates the capabilities of existing remote technology to meet AMD monitoring requirements. A second objective was to identify and evaluate remote technologies for application to AMD scenarios that are not currently being applied to AMD sites. The final objective was to identify gaps in current remote monitoring capabilities and provide recommendations for further development of the most promising techniques specific to AMD applications.

**Outputs:**

The study resulted in a summary of the state-of-the-art and a compendium of information on methods currently in use, organizations active in the field, suppliers of equipment and services, and lists of available products and equipment. Guides are presented in tabular form to address the applicability and effectiveness of various techniques to detect and monitor AMD. Each technique is also discussed separately.

The handbook is the result of an in-depth literature search, an information survey of more than 900 organizations, the synthesis of catalogues from suppliers of equipment and services, and numerous discussions with scientists working in the field.

**Recommendations:**

## *MONITORING*

The existing experience and information base should be expanded by the application of these technologies to specific sites.

## *MONITORING*

**Project 4.6.4**: Piezocone Field Test
Budget: $26,650
Sponsors: ........................................................................INCO
$9,000
Ontario ...................................................... $17,650
Expenditures: $26,650
Manager: E. Kustan, INCO
Contractors: INCO/UBC

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**Objective:**
The intent of this project was to demonstrate the capabilities of available *in-situ* testing techniques for use in the characterization of materials produced or affected by mining sulphide ores. The Resistivity Piezometer Cone Penetration Test (RCPTU) and specialized discrete water sampling techniques were evaluated for their ability to characterize sulphide ore tailings which have undergone oxidation processes.

**Outputs:**
The project demonstrated that *in-situ* testing tools can typically be deployed at much lower costs than conventional investigation methodologies. An improved method for characterizing mine tailings resulted due to the coupling of the subsurface information that this technology provides with a lower cost and higher data repeatability as compared to traditional discrete sampling techniques.

This study concentrated on INCO's Central Tailings Area in Copper Cliff, Ontario. During approximately 13 days of research on these tailings a total of nearly 550 metres of RCPTU and CPTU soundings and 10 BAT water samples were achieved. A similar sampling program with traditional technologies would require approximately 50%-100% longer. An additional 65 metres of soundings were carried out at Falconbridge's Fault Lake tailings area.

Although more detailed geochemical evaluations are recommended for comparison to traditional techniques, the results of this study suggest that RCPTU is an effective tool for comprehensive and economic characterization of sulphide-based tailings and surrounding native materials. The RCPTU provides full stratigraphic logging, a suite of geotechnical and hydrogeological parameters, and measurements of bulk resistivity which are indicative of the nature of dissolved constituents in the pore fluids.

**Recommendations:**
An overall evaluation of the RCPTU technology for any future geoenvironmental characterization work should be made in comparison to whatever technologies were in existing use on both a technical and economic basis. Further evaluation of this technique for specific site characterizations should also be made.

*MONITORING*

**Project 4.8.2**: Sediment Sampling Probe Field Application
Budget: $51,000
Sponsors: ........................................................................ CANMET
$17,040
Falconbridge ................................................ $12,000
INCO ........................................................ $ 5,000
Ontario ...................................................... $17,040
Expenditures: $51,080
Manager: C. Weatherell, CANMET
Contractor: AECL

**Objectives:**
To evaluate the use of a sediment probe as a method for determining the location of submerged AMD contaminated groundwater discharge zones into lakes, rivers and other waterbodies.

**Outputs:**
AECL has developed a method for locating and measuring groundwater discharges which are often obscured by the presence of overlying surface water. The technology may allow accurate and inexpensive environmental monitoring to be conducted at specific locations where environmental impact is occurring or is likely to occur.

An electrical conductance, bottom-contacting probe was towed behind a slowly moving boat over more than 28 line kilometres of lake and river bottom. In the fall of 1992 and in June, 1993 electrical conductance surveys were done in two general areas: between the public access and the lake outlet of Kamiskotia Lake; and in the Little Kamiskotia river from the lake outlet to about 3 kilometres downstream. The Kamiskotia Lake is about 25 km northwest of Timmins, Ontario. A laser positioning system was used on the lake but could not be used on the river due to the forested banks and adjacent swamps. As well, walking surveys allowed access in areas of water less than 0.3 meters deep. Shoreline surveys using a conductivity walking stick connected to a portable conductivity meter were performed along the eastern lake shore. The probe reconnaissance was used to target several areas of possible leachate discharge. These were studied quantitatively in order to evaluate the utility of the probe and to provide site-specific information. Discharges were confirmed by direct measurement of flux seepage meters or by measuring upward gradients, moderately high hydraulic conductivities or solute chemistry. Discharges ranged from 677 - 13,800 $\mu$s/cm and from 4.8 - 6.9 pH. For a variety of reasons discussed there is little correlation between pH and conductivity.

**Recommendations:**
Analyses of major ions, metals, and isotopes should be conducted to aid in distinguishing the underground sources. Adaptation of the probe to measure other specific contaminants should also be considered.

## *TECHNOLOGY TRANSFER*

**Project 5.6.2:** Third International Conference on the Abatement of Acidic Drainage
Budget: $15,000
Sponsors: Association Minière du Québec $4,000
Ontario ................................................ $5,000
CANMET ............................................ $3,000
Expenditures: $12,000
Manager: K. Wheeland, Environmental Coordinator
MEND Secretariat

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**Objective:**

MEND would cosponsor with the United States Bureau of Mines, the Third International Conference on Abatement of Acidic Drainage.

**Outputs:**

To promote communication in the areas of acidic drainage and land reclamation, two major conferences were combined into a joint conference that was held in Pittsburgh in April 1994.

Over 1,200 people attended this conference, out of which about half were concerned with Acidic Drainage. Eighty-five refereed papers, 75 posters and 5 training courses were presented on acidic drainage issues. MEND participants and contractors contributed 43 papers and posters. There was a special panel discussion on international acid drainage research chaired by MEND.

As a cosponsor, MEND participated in planning sessions, reviewing papers, chairing sessions and presenting papers. This conference was an excellent opportunity for MEND members to exchange new information with others working in the field of acidic drainage.

No new breakthroughs were presented at the conference that suggest alteration of the MEND program of research and development. At the same time, old misconceptions such as the idea that passive systems are widely applicable continue to be promoted.

The proceedings of the joint conference are available at no charge from the Bureau of Mines Office in Pittsburgh, or from the MEND Secretariat.

**Project 5.8.1**: Economic Evaluation of MEND-developed Technology
Budget: $40,000
Sponsors: ........................................................................ Ontario
$40,000
Expenditures: $40,000
Manager: J. Salley, CANMET
Contractor: Geocon

**Objective:**
The objectives of this study were to evaluate the costs of currently applied, or perceived feasible, AMD technologies and their comparison with a reference to planning future research directions in the AMD area, and to evaluate the financial liabilities to the Canadian mining industry and Canadian public as related to reactive mine wastes.

**Outputs:**
The study was carried out based on actual mine closure projects selected with a reference to the study objectives. Generic tailings/waste rock disposal sites were also considered to address specific cost issues such as the availability of borrow materials or the area-volume ratio in the case of a waste rock dump.

The following representative unit cost ranges were derived for the two basic AMD technologies (1994$/ha of tailings "footprint" or 1994$/tonne of waste rock):

| | **Tailings** | **Waste Rock** |
|---|---|---|
| **Collect and Treat** | 180,000 - 280,000<br>(210,000) | 0.4 - 2.0<br>(0.7) |
| **Minimal Maintenance (Walk-away)** | 100,000 - 300,000<br>(200,000) | 1.0 - 1.5<br>(1.30) |

where the values in brackets represent suggested typical ("average") unit costs.

In general, the composite soil cover and plastic liner technologies were confirmed to be the most expensive. From the cost perspective, it seems unlikely that these technologies would be considered preferable for many mine sites. The study results also indicate that it is unlikely that a walk-away option would be selected for a major waste rock dump which generates net acidity at the time of closure.

A spreadsheet template is available with the final report so that site-specific factors can be considered.

**Recommendations:**
The study results indicate that the self-sustained water cover and the collect-and-treat technologies may represent the best options from the perspective of the implementation costs. Hence, with regard to future AMD research directions, an emphasis should be made on these two technologies.

## *NEW IDEAS & INNOVATION*

**Project 6.1**: New Ideas Solicitation - Round 1
Budget: $203,100
Sponsors:

| | |
|---|---|
| CANMET | $44,400 |
| DIAND | $ 9,200 |
| Teck | $20,000 |
| INCO | $10,000 |
| Lac | $10,000 |
| Noranda | $10,000 |
| HBM&S | $15,000 |
| Ontario | $20,000 |
| Québec | $20,000 |
| AMQ | $10,000 |

Expenditures: $140,900
Manager: K. Wheeland
Contractors: Various

**Objective:**
The objective of New Ideas is to solicit and develop new ideas and innovation that will provide technology to significantly reduce the cost of preventing, controlling and treating acid mine drainage.

Results: **Table 18: New Ideas Projects: Results from Round 1**

| Project | Status | Results |
|---|---|---|
| #01 U.S. Research | Complete | Research identified for follow up by MEND. |
| #02 Permafrost | Further work | Permafrost can only be assured under deep cover in northern zones. Prediction committee considering further. |
| #03 Wax Cover | Complete | Results interesting. No further work needed. |
| #04 Modified Clay | Complete | Promising results. Second proof-of-concept stage in 1994. |
| #05 Phosphate Coating | Complete | Uneconomic. |
| #06 Japanese Tech | Further work | Promising technology leads being investigated. |
| #07 Artificial Hardpan | Complete | Technology uneconomic. |
| #08 Passivation | Complete | Unsuccessful. No further work planned. |
| #09 Ion Exchange Resin | Complete | Promising results. Second proof-of-concept stage to be done. |
| #10 Chelating Ribbons | Complete | Unsuccessful. |
| #11 Waste Co-mingling | Complete | Benefits questionable. Difficult to link tests to field. conditions. |
| #12 Chelating/Filtering | Complete | Technology unsuccessful. No further work planned. |
| #18 Polymer gels | Complete | Technology unsuccessful. |

| Number | Titles: |
|---|---|
| 1.12.1b | DBARD - DataBase for Acid Rock Drainage: Continued Compilation of AMD Prediction Data |
| 1.14.3 | Mine Doyon: A Comprehensive Review |
| 1.15.2 | AMD from Open Pits - Expansion and Verification of MINEWALL 2.0 |
| 1.19.2 | Evaluation of Scaling: Chemical Prediction Test Results at Bench, Pilot and Field Scales |
| 1.21.2 | Laboratory and Modelling Studies of Pyrrhotite Oxidation |
| 1.31.2 | Residual Weathering Products in Waste Rock Dumps |
| 1.32.2 | Pyrite Oxidation - Lithological and Mineralogical Approach |
| 1.42.1 | Critical Review of Geochemical Modelling |
| 2.11.4a | Evaluation of Underwater Disposal Site - Buttle Lake |
| 2.11.5a | Shallow Water Covers - Equity Silver (Phase I) |
| 2.11.9 | Underwater Disposal Sites - Design Criteria |
| 2.12.1 | Man-made Lakes Disposal Sites - Louvicourt Project |
| 2.13.2d | Monitoring of the Flooded Solbec Cupra Tailings Site |
| 2.15.1 | A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites |
| 2.21.3 | Peer Review of Waite Amulet and Heath Steele Soil Covers |
| 2.21.4 | Protocols for Engineered Soil Covers over Tailings and Waste Rock |
| 2.22.2 | Evaluation of Dry Covers Built from Mine Tailings |
| 2.23.2c | A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines |
| 2.31.1b | Dry Covers on Waste Rock - Heath Steele |
| 2.35.2 | Lysimeter Evaluations of Cover Alternatives - Noranda |
| 2.36.1 | In-pit Disposal - Case Studies |
| 2.36.2 | In-pit Underwater Disposal of Oxidized Waste Rock |
| 3.14.1 | Evaluation of Passive Systems for Treatment of AMD |
| 3.21.1b | Removal of Metals from AMD - Ion Exchange |
| 3.31 | Use of Lime Sludges for Capping |
| 3.41.1a | In Situ Treatment of AMD |
| 5.2.1a-d | Communications Plan - CIMM Lectures, Brochure, TV Series |
| 5.7.1 | MEND Newsletter |
| 6.2 | New Ideas Solicitation - Round 2 |

***PREDICTION*** ***Chemical Prediction***

**Project 1.12.1b**: DBARD - DataBase for Acid Rock Drainage: Continued Compilation of AMD Prediction Data
Budget: $40,000
Sponsors: ........................................................................................ Environment Canada ........................................................................................ $20,000
CANMET ............................................... $20,000
Expenditures: $25,000
Manager: G. Feasby, CANMET
Contractor: University of British Columbia

**Objective:**

This project will develop the existing database for acid rock drainage prediction data, DBARD, through:

- additional input of selected available static and kinetic test data;
- further development and user accessibility of the software; and
- ongoing maintenance and distribution.

**Status:**

The database, DBARD, was developed over the last two years to accept, store and retrieve relevant data from acid prediction testwork, including data from one-time or repetitive laboratory experiments and field tests. Version 1.0 of DBARD was a simplistic database with rudimentary routines for data entry which was not released. The database was greatly expanded in version 2.0 with improved data handling and editing, but little data was actually entered.

Since April, 1993, the database has resided at the University of British Columbia under the auspices of the Chair in Mining and the Environment. During this time the focus was on data input. The database now contains information, although not comprehensive, on mine component characterization and AMD prediction for 119 mines in British Columbia (1.12.1a).

The software is in the process of being transferred from the dBase II DOS based platform to Paradox, version 5.0, a Windows based platform. The Windows based environment ensures that data may be input or extracted in a more user-friendly manner. Associated user's manuals are also being upgraded. Direct access to the database through Internet is also being considered.

Over the next year, selected data have been input from the rest of Canada, and internationally, to ensure that a wide range of different and comprehensive prediction datasets are included.

The project is scheduled for completion by March 31, 1996.

***PREDICTION*** ***Modelling***

**Project 1.14.3:** Mine Doyon: A Comprehensive Review
Budget: $65,000
Sponsors: ........................................................................ CANMET $65,000
Manager: C. Weatherell, CANMET
Contractor: Geocon

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**Objective:**

A large and detailed research program on the south waste rock dump at Mine Doyon has been carried out over the past three years through the University of Laval in conjunction with the mine personnel. The objective of this project was to complete a technical review of the monitored data collected and the associated site assessment made to date.

**Status:**

A detailed, long-term field program has been carried out on the south dump at Mine Doyon over the last three years (1.14.1, 1.14.2). Monitoring data collected over this time included climatic, biological, geochemical, hydrological and physical parameters within the dump. From the information collected, simulation capabilities are being developed such as:

- geochemical (eg. rates of oxidation and storage of secondary products);
- physical (eg. heat production and temperature profiles); and
- hydrologic (eg, infiltration and residence times).

As one of the most studied waste rock piles in the world, the 21 million tonne dump provides an excellent opportunity for the further development of predictive capabilities. This review will provide a summary of the work done to date. Through recommendations for future priorities, it will ensure the quality and completeness of the field data collection and their interpretation as they relate to the prediction of AMD from waste rock dumps.

A consortium of four contractors, each experts in their respective fields, has been chosen by MEND members, the funders and in cooperation with the property owners. The project is scheduled for completion by September 18, 1995.

The deliverable of this project will be a report which will include a critical review of all project reports to date related to Mine Doyon. The report will include specific recommendations for further research, monitoring or other work, in the context of current waste rock prediction capabilities.

***PREDICTION*** ***Modelling***

**Project 1.15.2**: AMD from Open Pits - Expansion and Verification of MINEWALL 2.0

Budget: $88,000

Sponsors:

| | | |
|---|---|---|
| | CANMET | $53,000 |
| | BHP Minerals | $14,600 |
| | Noranda | $20,060 |

Expenditures: $72,960

Manager: C. Weatherell, CANMET

Contractor: Morwijk Enterprises Ltd.

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**Objective:**

This project addresses three objectives: expansion, improvement, and verification of the original MINEWALL code with appropriate user instructions; the collection of field data at two representative minesites; and the subsequent calibration of MINEWALL Version 2.0 using this field data.

**Status:**

In 1990, a literature review on the physical and geochemical impacts of mines, a short-term field investigation at Equity Silver, B.C., and the preliminary development of the program MINEWALL to simulate effluent quality from open pits were completed (project 1.15.1). The above literature review has been updated to the end of 1993. The known limitations of the model code such as the arbitrary equations describing pit flooding and decreasing sulphide oxidation through time, and the inability to explicitly simulate effluent quality from underground mine walls are also being addressed. Version 2.0 has been written as several individual, updatable modules and most of the programming effort to date has focused on data entry.

The collection of field data is complete at the Island Copper and Bell Mine open pits in British Columbia.

The complexity of the model has resulted in enormous amounts of computer code which cannot be handled by the current DOS-based programming language (Visual Basic). After consultation with the Prediction Committee, the contractor will simplify the computer code to retain user-friendliness without simulation of complex scenarios. Generation of a user's manual will be done on completion of the coding, testing and verification of Version 2.0 of the program. Verification will consist of mathematically comparing MINEWALL predictions against known outcomes using simplified data sets. To date, each existing module has already been tested with simplified data sets. More extensive datasets, and finally, real data will be used in the future.

The project is expected to be complete by March 31, 1995.

## *PREDICTION* *Chemical Prediction*

**Project 1.19.2**: Evaluation of Scaling: Chemical Prediction Test Results at Bench, Pilot and Field Scales
Budget: $21,000
Sponsor: Environment Canada
$15,000
Expenditures: $10,000
Manager: B. Godin, Environment Canada
Contractor: Synergetic Technology

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**Objective:**

The current approach in setting up tests for the evaluation of ARD material will be assessed and an evaluation of the validity of current practices in scaling between bench, pilot and field scale for spatial, temporal, physical, chemical and biological processes involved in acid generation will be completed.

**Status:**

Based on the derived scaling relations a sensitivity analysis has been performed. The results indicate the required precision of test results necessary for predictions. It is readily apparent that the ability to determine the applicability of small scale tests to large dumps is limited by the lack of quantitative information of the significance of various processes in controlling the chemistry of water emerging from smaller scale dumps (1.19.1). Also, tests for acid rock drainage prediction (e.g. humidity cells, column tests) as well as small scale treatment systems are used frequently to determine the success or failure of a particular approach. Little examination of the precision in the analysis and the size effects that may be significant at a smaller scale has been carried out. Appropriate scaling between the physical, chemical and biological processes is important. Often, certain effects occur only after reaching a critical point. It is not unreasonable to believe that scaling of waste rock experiments may not be constant throughout a continuum of volume and time, and that parameters may be affected by such scaling laws. A better understanding of these scaling 'laws' could result in the application of non-field scale experiments with increased confidence. The report will show the change in temperature regimes due to the size of the waste rock pile. The analysis was also performed for various pH values. The effective reaction transport processes have been derived by means of a generalized Thule modulus which allows determination of a critical pile size as a function of other physical and chemical parameters responsible for ARD.

The project should be completed by early May, 1995.

***PREDICTION*** ***Modelling***

**Project 1.21.2**: Laboratory and Modelling Studies of Pyrrhotite Oxidation
Budget: $100,000
Sponsors: ........................................................................ CANMET
$30,000
Ontario ........................................................ $30,000
INCO ........................................................ $20,000
Noranda ........................................................ $20,000
Expenditures: $14,990
Manager: S. Ahmed, CANMET
Contractor: University of Waterloo

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**Objective:**
The control of pyrrhotite oxidation kinetics will be studied under environmental conditions representative of waste disposal. Special emphasis will be placed on acquisition of data that are required to model dynamic tailings oxidation in the environment using existing models, and enhanced versions based on this research.

**Status:**
Numerous pyrrhotite samples from different localities in North America were obtained to determine if differences in impurities such as Ni, Co and Cu ions that have substituted for Fe in the pyrrhotite structure have an effect on oxidation rates. All samples have been cleaned and examined by X-Ray Diffraction (XRD) analysis. The cleaning procedure was revised to ensure the complete removal of fines. Surface areas measured by Brunauer-Emmett-Teller (BET) analysis are approximately 5 times higher than estimated geometric areas most likely due to surface irregularities on pyrrhotite particles. Surface areas are also dependant on the pyrrhotite variety.

The quantitative analysis of the crystallographic determination of the monoclinic and hexagonal pyrrhotite fractions has been revised. The new procedure is based on a Gaussian analysis of both of the monoclinic peaks on the XRD spectra. Elemental analysis by chemical digestion followed by inductively coupled argon plasma (ICAP) is being conducted.

The rate of non-oxidative dissolution under acidic pH conditions, as measured by solution $Fe^{2+}$, was higher than expected. Comparison of rates of non-oxidative dissolution and oxidation by molecular oxygen indicate that the driving force behind non-oxidative dissolution is hydrogen sulphide evolution. Ferric iron oxidation and biological oxidation are comparable. They are approximately twice the reaction rate of oxidation by molecular oxygen. The main biological enhancement is due to iron recycling from ferrous to ferric iron. Oxygen consumption experiments on pyrrhotite particles suggest a higher rate of oxidation than pyrrhotite in water-filled reactors.

Work on oxidation procedures and oxygen consumption will continue. Column studies will be used to examine pyrrhotite oxidation in simulated tailings environments.

***PREDICTION*** ***Basic Research***

| | |
|---|---|
| **Project 1.31.2**: | Residual Weathering Products in Waste Rock Dumps |
| Budget: | $40,000 |
| Sponsors: | British Columbia $20,000<br>Placer Dome ........................................... $10,000 |
| Expenditures: | $19,910 |
| Manager: | W. Price, B.C. MEMPR |
| Contractor: | University of British Columbia |

**Objective:**

This project is assessing weathering products retained in a waste rock pile from a dump-leach mine site. Specific objectives are: the identification and characterization of the weathering products; the development of probable mechanisms that relate bulk mineralogy to the secondary products formed; and the estimation of the reactivity/stability of these secondary products under differing environmental conditions.

**Status:**

Investigations into the physical and chemical fate of residual weathering products within waste rock dumps are important factors in the development of a predictive chemical evaluation scheme. Investigations were initiated in 1993 at Gibraltar mines, British Columbia.

Four sites have been excavated at Gibraltar with the aid of a backhoe, and are approximately
4m x 4m x 4m. The sites are representative of rock dumps that have received acid leaching, and one that has weathered naturally. Samples were collected based on morphological features, transported to the laboratory, air-dried and separated by size.

The fine fraction was analyzed by X-Ray Fluorescence (XRF) for elemental content and X-Ray Diffraction (XRD) for dominant mineral species. XRD analyses were characteristic of the geological parent material. Identified in several samples were, gypsum, jarosite, hematite and interstratified 2:1 phyllosilicates. The fine silt sized fraction exhibited a greater assemblage of mineral species than the sand sized fraction. Selective dissolution analysis (SDA) extractions by citrate-bicarbonate-dithionite and acid ammonium oxalate were used to examine 'free' hydrous oxides of Fe and Al and amorphous inorganic hydrous oxides, respectively. Heavy mineral separations and/or SDA in association with XRD appears promising as potential techniques to concentrate and identify weathering products.

Laboratory analyses on elemental composition and relation to mineralogy and pit morphology will continue as will sequential selective dissolution analyses and micro-techniques. Statistical analyses will be conducted to ascertain general relationships and trends. The project is expected to be completed in 1996.

**PREDICTION** **Basic Research**

| | |
|---|---|
| **Project 1.32.2**: | Pyrite Oxidation - Lithological and Mineralogical Approach |
| Budget: | $40,000 |
| Sponsors: | British Columbia $20,000<br>Homestake ................................................$5,300 |
| Expenditures: | $19,084 |
| Manager: | W. Price, B.C. MEMPR |
| Contractor: | University of British Columbia |

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**Objective:**

To investigate the applicability of detailed lithological and mineralogical characterization to the prediction of acid rock drainage.

**Status:**

The original work plan from the proposal was modified by replacing the cyclic voltammetry component, to examine differences in pyrite weathering, by humidity chamber weathering of polished thin sections. The project was divided into the following stages: geochemical characterization; pre-weathering lithological and mineral characterization; laboratory humidity cell weathering; and post weathering characterization.

Determined NP and calculated CaNP from acid volatilized $CO_2$ data agree well for both the Eskay Creek and Mount Milligan samples. This suggests that the available buffering capacity results from carbonate and not silicate minerals. Eskay Creek samples showed that generally footwall rhyolite breccia is potentially acid generating while hanging wall basalts are not. The acid generating potential of rhyolite flow and massive rhyolite samples is uncertain.

Thin section petrography shows the presence of microfractures that provide pathways for oxygen and water to contact the sulphides. Sulphides are dominantly disseminated and frequently associated with carbonate.

Laboratory weathering experiments were conducted for 4 months at a mean temperature of 37 °C. Samples identified through ABA test results were prepared as polished sections. These samples included; rhyolite breccia, ryholite flow, and massive rhyolite samples from Eskay Creek and monzonite, latite, and andesite from Mount Milligan. Soluble oxidation products were collected at the end of every month by submerging the polished sections in water for 4 hours. Severe sulphide oxidation and silicate weathering were observed for most samples within 31 days of weathering. A slight increase in pH towards the end of the experiments may be associated with delayed buffering by silicates and/or secondary products.

The first draft of this M.Sc. thesis is expected by July 1995.

***PREDICTION*** ***Modelling***

| | |
|---|---|
| **Project 1.42.1**: | Critical Review of Geochemical Modelling |
| Budget: | $60,000 |
| Sponsors: | ........ CANMET $30,000<br>Ontario ........ $30,000 |
| Expenditures: | $54,000 |
| Manager: | M. Blanchette, CANMET |
| Contractors: | Noranda Technology Centre, Alberta Research Council, and University of Western Ontario |

**Objective:**

The two objectives of the proposed work are: to identify the various geochemical processes occurring in waste rock piles at all stages of acid generation, and to list and thoroughly review existing geochemical models which are being used, or can be adapted, for predicting metal species and their concentrations in waste rock piles.

**Status:**

The geochemical processes which most control ARD quality are precipitation and dissolution, chemical diffusion, and surface reactions. Precipitation and dissolution control neutralization of acidic solutions and fixation of metals within solids. Chemical diffusion and surface reactions control the rates at which all precipitation and dissolution reactions occur. Quantitative reaction rates are required to accurately predict water quality from waste rock piles. Reaction rate equations need to incorporate the important influence of rate-modifying mechanisms such as bacterial catalysis. Drying and wetting are the most important physical processes that affect water chemistry, by concentrating aqueous solutions to the point of precipitating solids and subsequently dissolving and removing these solids from solution contact. Field data required to describe geochemical processes in waste rock include detailed water analyses, rock mineralogy and trace element chemistry, exposed surface area, temperature, oxygen availability and water infiltration rates. Thermodynamic and reaction rate data for important secondary minerals in ARD are insufficient.

Existing geochemical models are divided into five classes: equilibrium thermodynamic models; mass transfer models; coupled mass transport-mass transfer models; supporting models; and empirical and engineering models. Each class of geochemical models can be viewed as addressing a different type of ARD prediction objective. These models are presented in tabular format for easy comparison of features.

The project will be completed by the end of March 1995.

## PREVENTION AND CONTROL -Underwater Disposal

**Project 2.11.4a:** Evaluation of Underwater Disposal Site - Buttle Lake
Budget: $250,000
Sponsors: Placer Dome
$ 94,000
CANMET ............................................. $150,000
Environment Canada .................................. $ 6,000
Expenditures: $200,000
Manager: J. Robertson, Placer Dome
Contractors: Rescan Environmental/ASL Laboratories
University of British Columbia/Environment Canada (NWRI)

### Objective:

The objective of the Buttle Lake program is to address the recommendations made in the first peer review and to provide the additional information needed to support the application of the subaqueous disposal method. The focus of the project at Buttle is on field and analytical techniques to improve measurement of metal fluxes at the sediment/water interface.

### Status:

Buttle Lake, located in Strathcona Park on Vancouver Island, presents an opportunity to study the reactivity of mill tailings from a deep discharge which is now covered by a veneer of almost one decade's worth of natural sediment. Of particular interest is the reactivity of the tailings that have been admixed with natural, surficial sediments as they have been exposed to oxygenated bottom-water since the time of original deposition.

In keeping with the recommendations of the peer review (2.11.1d), a work plan that addresses the key issues of QA/QC and salient aspects of sediment chemical-seasonality was developed. A sampling campaign was completed on Buttle Lake in October 1993. The work addresses tailings reactivity by high-resolution observation of trace-metals and other sensitive "tell-tale" indicators within the interstitial waters of the sediments and across the sediment-water interface. This was completed using a combination of sampling methodologies including: discrete water-column sampling and profiling, extrusion and centrifugation of cores, as well as the use of peepers to integrate sediment and water-column chemistry. A cross-comparison was done on two methods of handling samples from the peepers: under inert atmosphere and sample extraction under normal atmosphere.

Preliminary results from the sampling campaign on Buttle Lake, particularly the porewater peepers at the sediment-water interface, confirm the tentative findings from earlier studies for tailings reactivity.

***PREVENTION AND CONTROL -Underwater Disposal***

**Project 2.11.5a**: Shallow Water Covers - Equity Silver (Phase I)
Budget: $80,000
Sponsor: Placer Dome
$ 44,000
Expenditures: $44,000
Manager: J. Robertson, Placer Dome
Contractor: Hay and Company Consultants Inc.

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**Objective:**

The objective of the project is to examine the present conditions at the site and to review applicable physical variables such that generic criteria can be generated for both operational mines and those undergoing closure. The study involves both empirical and theoretical analysis, making use, where possible of site data and observations, supported, or augmented by theory.

**Status:**

The Equity Silver mine located near Houston, B.C. ceased operations in January 1994 and provides an excellent opportunity to investigate several of the physical variables associated with subaqueous disposal of mine tailings. At the time of closure about 80 million tonnes of waste rock was excavated from the open pit and placed into waste dumps. The tailings resulting from the ore processing have been submerged underwater in a shallow lake impoundment which contains approximately 33 million tonnes of tailings and covers an area of about 120 hectares. The tailings are estimated to contain between 4 and 5% pyrite.

The Equity Silver tailings pond is one of the first sites to close that has used the concept of water covers (cover of 1 to 1.5 m depth) over fresh tailings. Assumptions were used during the design of the impoundment. This project, started in 1994, is an opportunity to return to the closed-out site and complete an engineered evaluation on the effectiveness of shallow water covers. Physical variables are being investigated to ensure that the tailings are contained within a stable sediment bed that is resistant to removal by flow (e.g. wind-wave driven resuspension and subsequent entrainment mechanisms, thermal stratification of water, grain size distribution). Most of the work completed in Phase I was done by reviewing available reports and the relevant literature for the identification of the critical physical parameters. A field measurement program was used to obtain additional monitoring data to supplement the existing information. The final report for the first phase is currently under review and should be available in 1995.

Using the Equity Mine site to illustrate the dynamics of several of the key physical variables will lead to the start of the development of both operational and closure guidelines for subaqueous disposal of tailings. This study will identify what are presently known to be useful criteria and will identify areas in which additional field work (2.11.5b) is required to finalize the design criteria.

### *PREVENTION AND CONTROL -Underwater Disposal*

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|---|---|
| **Project 2.11.9**: | Underwater Disposal Sites - Design Criteria |
| Budget: | $50,000 |
| Sponsor: | To be determined |
| Expenditures: | $0 |
| Manager: | J. Robertson, Placer Dome |
| Contractor: | To be determined |

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**Objective:**

The final ultimate objective of the evaluation of existing underwater disposal sites is the development of criteria to use this method for general disposal of reactive tailings. Such criteria would be applicable to new projects as well as existing sites with acidic drainage problems.

**Status:**

In 1991, at the invitation of MEND, the Rawson Academy of Aquatic Science completed a first peer review on subaqueous disposal (2.11.1d). Recommendations made in the peer review formed the basis of geochemical field studies which were carried out in Anderson and Buttle lakes. Companion studies included technical literature reviews, comparison of field techniques, and establishment/documentation of QA/QC programs.

A planned outcome of this program is to develop a manual on how to employ the technique for final disposal of reactive tailings underwater. Water cover should minimize the transport of oxygen, and subsequently limit acid generation. Systematic evaluation of existing sites will provide a basis for assessing the overall effectiveness and developing a design criteria manual for underwater disposal techniques. Several projects are currently underway and the results from these studies are needed for the development of the manual.

Scientific and regulatory review and planning is a major part of the program, and is assisting in achieving a fair and objective study of the concept and methodology for subaqueous disposal of reactive tailings in lake. A second peer review (2.11.1e) is planned for 1995 with the objective to assess the work undertaken over the past three years in context with the original points of concerns identified in the first peer review.

The acceptance of this promising method of acid drainage control, is a prerequisite to the development of the final objective of a design and application manual. Several important steps remain before beginning the development of the manual.

### *PREVENTION AND CONTROL -Underwater Disposal*

**Project 2.12.1**: Man-made Lakes Disposal Sites - Louvicourt Project
Budget: $350,000
Sponsors: ........................................................................ CANMET
$27,000
Expenditures: $27,000
Manager: M. Filion, Teck
Contractor: Golder Associés

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**Objective:**
The objective of the field and laboratory project for the Louvicourt man-made lake tailings impoundment is to demonstrate the effectiveness of shallow water covers as a permanent means of preventing the oxidation of sulphide minerals and the consequent formation of acidic drainage.

**Status:**
Underwater disposal of mine wastes (tailings and waste rock) in man-made lakes is presently an option favoured by the mining industry to prevent the formation of acidic drainage. Because of the potential controversy associated with using natural lakes for subaqueous disposal of tailings, there is considerable interest in evaluating whether artificial basins offer similar advantages to natural lakes. Artificial or man-made basins provide substantially different conditions (e.g. shallow water cover, exfiltration) for the management of reactive tailings as compared to lakes. There are numerous sites where tailings have been deposited in a partially or completely submerged state in conventional tailings areas. However, there have been no geochemical studies, similar to those carried out for natural lakes (2.11), undertaken for these artificial basins.

The project has been divided into three phases. The last phase will be completed after the MEND program ends in 1997. Phase I, completed for $27k, was the conceptual design, costing and proposal formulation for phase II, the integrated laboratory and field studies ($469k). For phase I, a one-day project definition session was held in Montréal in March 1994. A group of experts in their respective fields identified by MEND and the mine operators and owners, were invited to attend. A final report, the phase II proposal, was received in December.

A combination of laboratory experiments and two field tests cells is proposed to achieve the objectives of the project. The laboratory column studies have been designed to assess shallow water covers (300 mm and 1 m to compare) in relation to flooded tailings covered with 300 mm of organic material. Two field test cell experiments have been designed: Cell #1 will simulate as nearly as possible conditions upon closure with a shallow 0.3 m of water; and Cell #2 will also simulate closure, but will incorporate wet organic material (0.3 m) along with a 0.3 m shallow water cover. The benefits of an additional layer of protective material in the water cover system will be assessed as part of the tool box of technologies being provided by MEND.

### *PREVENTION AND CONTROL - Wet Barriers*

**Project 2.13.2d**: Monitoring of the Flooded Solbec Cupra Tailings Site
Budget: $150,000
Sponsors: ............................................................................Cambior $ 24,000
Québec.................................................. $ 70,000
Expenditures: $ 30,000
Manager: L. Bienvenu, Ministère des Ressources naturelles (MRN) du Québec
Contractors: EnviroMine/Les Consultants SM

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**Objective:**

The objective of this project is to monitor the Solbec Cupra tailings impoundment during and after flooding. The monitoring program will include surface and groundwater chemistry, hydrology, water balance (e.g. seepage, water depth), meteorological (e.g. precipitation), wave action (e.g. resuspension of particles), and the microbiological activity.

**Status:**

As distinct from underwater disposal, wet barriers is defined as establishing a water cover on oxidized tailings. As with underwater disposal, further oxidation is considered unlikely but the mobilization of the soluble salts becomes a major consideration. This closure option may be attractive if the fate of these oxidation products can be predicted. The proposed closure plan for the 66 hectare Solbec Cupra tailings site, with ≈30 to 50% sulphide, is flooding.

In the first phase, started in 1989, several fundamental studies using field lysimeters (e.g. water cover only, water cover and limestone) as well as a hydrogeological study of the tailings basin were completed confirming that flooding of the tailings impoundment is possible with natural precipitation and surface runoff over an eighteen-month period. Wave action and microbiological studies together with a synopsis of field lysimeter information were completed in 1995 (2.13.2abc).

In order to commence flooding of the site, Cambior, the owner of the site, completed the construction of one of the two necessary dams in late 1994. Tailings from the higher elevations were moved to the lower areas and about 13,000 tonnes of limestone was added and mixed to the surface of the tailings impoundment to neutralize most of the accumulated acidity in the oxidized tailings. Rehabilitation costs to date for the Solbec Cupra tailings impoundment are estimated to be about $ 2.1 M.

Several new piezometers were installed on the tailings impoundment in late 1994 and one sampling campaign was completed. Monitoring of the site is planned for 1995 during flooding.

***PREVENTION AND CONTROL -Wet Barriers***

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|---|---|
| **Project 2.15.1**: | A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites |
| Budget: | $487,000 |
| Sponsors: | Noranda Technology Centre (NTC) $253,000 |
| | INCO .......... $ 85,000 |
| | Lac Minerals .......... $ 15,000 |
| | Ontario .......... $ 30,000 |
| Expenditures: | $298,000 |
| Manager: | R. Michelutti, Falconbridge |
| Contractors: | NTC/CANMET |

**Objective:**

The project is using laboratory, numerical, and field methods on oxidized tailings to obtain the parameters necessary for evaluating the effect of different depths of water cover on the long-term quality of the overlying and interstitial water.

**Status:**

The project is being conducted jointly by NTC and CANMET. NTC is studying the diffusion coefficients and fluxes, and has started field tests at Mattabi. CANMET is studying the oxygen diffusion characteristics, the wave action and sediment erosion characteristics and contaminant transport flux measurements.

Covering sulphitic mine tailings with water effectively reduces oxygen influx to the tailings and the resulting acid generation. However, metals present in porewater solutions or in soluble mineral phases may still be released from the flooded tailings impoundment. Results from a column experiment where oxidized tailings are covered by 1 m of water showed that transfer of zinc, sulphate, and iron from the tailings to the water column could occur. The transfer could be controlled by the addition of a protective sand layer over the tailings. It is recommended that further work be carried out on the geochemical processes which influence metal releases (2.15.2). Results from the Mattabi tailings case study suggest that removal of zinc by treatment of surface and seepage water is still required for a long period after implementation of the water cover.

The construction costs for artificial hydraulic containment structures to obtain an adequate water storage over the tailings are often high. It is therefore recommended, before deciding to commit to these costs, to evaluate treatment and maintenance requirements using laboratory and field testing. Models (e.g. WATAIL) to investigate the effect of establishing a water cover at various times in the depositional history of an impoundment do exist. At the Mattabi site, the importance of applying a water cover early if it is to be applied at all, was demonstrated.

### *PREVENTION AND CONTROL -Dry Barriers*

**Project 2.21.3**: Peer Review of Waite Amulet and Heath Steele Soil Covers
Budget: $50,000
Sponsor: ........................................................................ Cominco
$47,000
Expenditures: $ 0
Manager: R. Gardiner, Cominco
Contractor: University of Saskatchewan

**Objective:**
The objective of this project is to complete a scientific peer review of the design and evaluation of engineered natural soil covers at a number of sites, including Waite Amulet and Heath Steele.

**Status:**
There are a number of sites world-wide in which natural soil covers have been used in the reclamation of potentially acid generating waste rock and tailings. The design objectives of these sites vary; however, at most sites it is hoped that the presence of the cover will accomplish three functions:

- provide a low-hydraulic conductivity barrier to minimize the influx of water;
- provide an oxygen diffusion barrier to minimize the influx of oxygen; and
- provide a stable soil surface on which vegetation can be established.

These functions are usually accomplished through the use of a "layered" cover in which a lower layer of low hydraulic conductivity and high moisture retention characteristics is overlain by a well-drained surface layer. This upper layer provides protection to the lower layer against climatic effects, such as freeze/thaw, dissipation and erosion while also serving as a layer for revegetation. The Heath Steele and Waite Amulet sites are the most prominent examples of cover designs which have been engineered to provide the benefits described above. The focus of these sites was on demonstrating the capability of "layered" soil systems to provide effective covers for waste rock and tailings.

The peer review, which began in January 1995, will:

- undertake a literature review of fundamental processes for dry covers;
- provide an independent review of the design, construction, monitoring, analyses, and interpretation of the performance of Waite Amulet and Heath Steele covers;
- complete an inventory of other "dry cover" sites and their performance and identify the key aspects of cover designs for those sites;
- analyze alternative means by which the essential components of dry covers could be provided, while at the same time, minimizing construction costs; and
- provide recommendations as to critical research needs as applied to the design, construction, monitoring and analyses of dry covers.

***PREVENTION AND CONTROL -Dry Barriers***

**Project 2.21.4**: Protocols for Engineered Soil Covers over Tailings and Waste Rock
Budget: $30,000
Sponsor: To be determined
Manager: To be determined
Contractor: Competitive bidding

### Objective:

The objective of this project is to develop protocols for the design, construction and maintenance of engineered soil covers over sulphide tailings and waste rock.

### Status:

The development of protocols will enable mine operators and regulators to assess the technical feasibility and cost of engineered soil covers on a site specific basis and will provide a sound basis for detailed engineering design and cost estimation, construction supervision and maintenance.

The development of protocols follows the completion of the peer review (2.21.3). The scientific peer review will determine whether any additional experimentation is required prior to the development of protocols for the design, construction and maintenance of engineered soil covers over sulphide tailings and waste rock. The peer review will ensure the quality and completeness of the field data and interpretations which will provide the basis for the protocols and will enhance the scientific credibility of several key project reports.

In the final report it is expected that the applicability of engineered soil covers will be briefly outlined and the critical soil parameters identified. Appropriate reference methods for soil testing, engineering design criteria to be satisfied in the design of robust engineered soil covers and key performance criteria, which may be used for field monitoring of effectiveness, will also be included in the guide. The report will include recommended protocols for soil testing procedures, cover design, construction and maintenance. It may also refer, where appropriate, to published methods adopted by standards and technical organizations of Canadian jurisdictions.

## PREVENTION AND CONTROL -Dry Barriers

**Project 2.22.2**: Evaluation of Dry Covers Built from Mine Tailings
Budget: $234,880
Sponsors: ....................................................................Québec
$133,000
Itec Minéral inc. ........................................ $ 20,000
Lac Minerals ............................................ $ 10,000
CANMET ..............................................$107,000
Expenditures: $270,000
Manager: L. Bienvenu, Ministère des Ressources naturelles (MRN) du Québec
Contractor: École Polytechnique

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**Objective:**
The objective of this study is to evaluate, under controlled laboratory conditions, the effectiveness of using fine tailings as an alternative for the capillary material in layered cover systems to control acid mine drainage (AMD).

**Status:**
In most of the projects currently underway in Canada and abroad, dry barriers are usually constructed from naturally occurring geological materials (till, silt or clay) maintained at a high degree of saturation to minimize the diffusion of oxygen through the cover. Because low permeability soils may not be economically available, alternate materials (e.g. fine tailings) having somewhat similar physical properties may be substituted.

More than 30 tailings sites were sampled and analyzed as possible cover materials and a literature review was completed. Preliminary tests, including mineralogical analyses, grain size determination and Atterberg limits, allowed the selection of four sites where the tailings were sampled again for more detailed studies. The results confirm that sulphide-free fine tailings offer some promising characteristics as cover materials. For example, it has been shown that, when the void ratio is reduced, the permeability of tailings can be as low as $1 \times 10^{-6}$ cm/s, which compares very well with that of silts and tills. Also from the sieve analyses and available data in the literature, it is expected that fine tailings can maintain a high degree of saturation when they are used in a layered system because of their relatively high water retention capacity. Suction curve studies on tailings have recently confirmed this. Recent work described in the literature shows that silty soils, with physical properties similar to some of the tested tailings, can be used with success to limit AMD.

The laboratory program included measurement of various properties (compaction parameters, consolidation behaviour, hydraulic conductivity, capillary characteristic curves and effective diffusion coefficient), numerical modelling for water and oxygen transport in multilayer covers and physical modelling in columns to validate the calculations. The results of this laboratory investigation can be used to make preliminary design calculations for large scale applications. From this work, it is inferred that the critical parameter in the design of a cover system is the volumetric water content, which should be maintained as high as possible (ideally above 90%) in the capillary layer in order to limit the flow of oxygen.

## *PREVENTION AND CONTROL - Others*

**Project 2.23.2c:** A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines
Budget: $78,200
Sponsors: .............................................................. Falconbridge $39,100
Ontario .................................................. $20,000
CANMET ............................................... $20,000
Expenditures: $ 35,000
Manager: D. Bordin, Falconbridge Limited
Contractors: E.I. Robinski Associates Ltd./University of Saskatchewan

### Objectives:

The objectives of this study are to verify modelling results of the behaviour of thickened tailings disposal against field observations. Specific objectives include determining the net infiltration due to climatic flux, the pathway and rate of infiltrating water and the role played by the zone of capillary saturation in the attenuation of infiltration and contaminant migration.

### Status:

One hundred and thirty-five mini-piezometers were installed at three test sites on the tailings deposit in late 1992. The three sites were located downslope and in increasing distance away from the top of the cone. Two salts were chosen as a chemical tracer, potassium bromide and potassium iodide, which have high solubilities and are not originally present in the tailings. The presence of the anions in samples would be indicative of contaminant migration through the system. The system was subsequently "seeded" during the fall of 1992 and two sampling campaigns were completed in 1993 and one in 1994.

The hydrogeology of the cone was studied (2.23.2ab) and it was predicted that average porewater velocities were quite low, ranging from 0.1 cm/yr to 69 cm/yr which would allow for low contaminant migration rates. The first set of results had higher than predicted velocities but subsequent sampling showed that the relative rates were actually slower and in the predicted range. It is believed that advection may have caused the initial higher velocity rates. Core samples, in addition to regular monitoring, will be completed in 1995 to determine if the rates are affected by advection or dilution.

The project will be completed in 1995 and the results will be used to calibrate models on the performance of the TTD method with respect to seepage and contaminant transport.

## *PREVENTION AND CONTROL -Waste Rock*

| | | |
|---|---|---|
| **Project 2.31.1b**: | Dry Covers on Waste Rock - Heath Steele | |
| Budget: | $367,700 | |
| Sponsors: | Noranda - BM&S (Heath Steele) | $121,300 |
| | CANMET | $154,500 |
| | New Brunswick | $ 91,900 |
| Expenditures: | $350,000 | |
| Manager: | M. Patterson, Heath Steele Mines | |
| Contractors: | ADI Nolan Davis/Heath Steele Mines | |

**Objective:**
The objective of the project is to evaluate the effectiveness of a soil cover as a method of long term management of acid-generating waste rock. Project 2.31.1b consists of applying the cover, designed in Project 2.31.1a to Pile 7/12 and monitoring the cover's performance for three years.

**Status:**
Construction of the engineered cover was completed in September 1991. The cover consisted of a 30 cm thick sand base, a 60 cm thick compacted glacial till, a 30 cm thick granular layer, and a final 10 cm thick gravel layer for erosion protection. The performance of the composite cover has been monitored on a continuous basis since. A second pile (18B) is also being monitored as a control.

The results clearly indicate reductions in the gaseous oxygen concentrations in the pile. Initial concentrations of 20%, prior to cover placement, have been reduced to about 1%. Pile temperatures decreased following cover placement, but now appear to be controlled primarily by climatic conditions, rather than oxidation rates. Of critical importance for evaluating the effectiveness of the soil cover, is the results of water chemistry from seepages emanating from the pile. The unique design of the cover allows a full water balance to be calculated, and this has shown an infiltration rate of about 2% of precipitation. However, the water quality of the effluent has not significantly changed, and this aspect will be further studied by continued monitoring (2.31.1c). A report on the "Engineering Design and Construction of the Composite Soil Cover" will be available in 1995. Monitoring of the pile was completed in late 1994 and the final report for Project 2.31.1b should also be available in 1995.

Project 1.22.1 was started after the construction of the cover, with the objective of developing an understanding of the processes governing the pyrite oxidation rates in acid waste rock piles. Field data was supplemented by the use of the FIDHELM model developed by ANSTO, to quantify the processes and to evaluate the effectiveness of the soil cover.

Further monitoring will be required to confirm the reduction in acid production from waste rock piles. A proposed 2-year program to continue the monitoring of the performance of the cover is recommended (2.31.1c).

### *PREVENTION AND CONTROL -Waste Rock*

| | | |
|---|---|---|
| **Project 2.35.2**: | Lysimeter Evaluations of Cover Alternatives - Noranda | |
| Budget: | $275,000 | |
| Sponsors: | Noranda | $ 152,000 |
| | Québec | $ 84,000 |
| | CANMET | $ 43,000 |
| Expenditures: | $250,000 | |
| Manager: | L. St-Arnaud, Noranda Technology Centre | |
| Contractors: | Noranda Technology Centre/McGill University | |

**Objective:**

The objective is to evaluate the relative effectiveness of different measures in preventing and controlling sulphide oxidation and hence acid generation in waste rock under field conditions.

**Status:**

The experiments were started in June 1991 and weekly monitoring of the drainage water from the lysimeters has been in progress since then. The control techniques being investigated are water cover, composite soil cover, wood bark cover, and the addition of limestone and phosphate rock (apatite). Potentially acid-generating waste rock samples used in the investigation were obtained from the Stratmat mine in New Brunswick and from Les Mines Selbaie in Québec. The investigation involved outdoor lysimeter tests and indoor laboratory column experiments.

Monitoring of the effluent water quality up to about 154 weeks indicated the control waste rock started producing acid very early in the tests (≈ 5th week). The rate of acid production was quantified and found to be higher in the laboratory than outside. Higher laboratory temperatures were most probably the reason for the higher rate.

The most effective control technique over the 154-week period was water cover, followed by 3% and 1% limestone, soil cover, and finally 3% and 1% phosphate. The water cover maintained the same effectiveness (>99%) in both laboratory and outside tests. The soil cover was more effective in the laboratory (98.0%) than outside (46.6%). The difference may be explained by the effects of adverse natural climatic conditions (e.g. freezing and thawing) which were not present in the laboratory. It is also believed that oxygen and water enter the soil covered waste rock mostly by the side walls of the lysimeters. The wood bark accelerated acid production by about 30% in the laboratory and 170% outside. The role of the iron oxidizing bacteria (*Thiobacillus ferrooxidans*) was invoked to explain this acceleration. The addition of a bactericide solution to the indoor and outdoor wood bark tests resulted in a sharp decrease in oxidation rate, which indicated a strong bacteria activity. In addition, a control wood bark containing only wood bark was monitored in parallel and the resulting drainage showed no acidity or metal contamination. Thus it was concluded that a wood bark cover is not considered a good technique. Aqueous geochemical modelling of effluents, collected during the three-years of testing, is presently in progress.

## *PREVENTION AND CONTROL -Waste Rock*

**Project 2.36.1**: In-Pit Disposal - Case Studies
Budget: $50,000
Sponsors: .................................................................... HBM&S
$10,000
Ontario .................................................... $20,000
CANMET ............................................... $20,000
Expenditures: $20,000
Manager: G. Tan, CANMET
Contractor: SENES Consultants Ltd.

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**Objective:**
The objective of this project is to complete a case study review on the use of mined out pits as a depository for potentially acid generating and non-acid generating materials. Water filled pits with existing water quality data will also be summarized.

**Status:**
A case study review on the use of mined out pits as a depository for mining wastes materials was started in October 1994. The focus to date has been to identify suitable "pits" where in-pit disposal has been used, or is proposed, and to collect relevant information. Good information has been obtained on: technical issues related to in-pit disposal; the diverse practices used and proposed; recently completed "successful" in-pit disposal programs; and issues/concerns associated with in-pit disposal of waste. What has been found is that the practice of in-pit disposal is more widespread than originally thought.

The study is progressing on schedule. Worldwide information gathering activities are continuing. Over 25 sites have been identified in Canada, the United States and Europe. Nine sites (seven in Canada, one in Sweden, and one in the United States), for more detailed case studies, have been identified in the Interim Report received in early January 1995. The selection was based on the quantity of information available (studies, reports, monitoring data etc.), and the suitability of the site for representing a typical situation within the Canadian context. Preference was given to historic sites where the flooded pit concept had been used. The selected sites are geographically distributed across Canada and represent several types of mines (ore) and reactive wastes. An American site was included as an example of state-of-the-art approach to predicting pit water quality.

The final report, due March 31, 1995 will include the completed document which lists the gathered information for all sites including the more detailed case histories. The information will be summarized and presented in a format that could allow for the future development of a database. The information collected on all known sites will be a very useful reference document for those in the mining industry contemplating the placement of waste in mined out pits.

## *PREVENTION AND CONTROL -Waste Rock*

**Project 2.36.2**: In-pit Underwater Disposal of Oxidized Waste Rock
Budget: $166,000
Sponsors: .................................................................. Noranda
$ 78,000
CANMET .............................................. $ 50,000
Expenditures: $30,000
Manager: M. Patterson, Heath Steele Mines
Contractor: Noranda Technology Centre

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**Objectives:**

The objectives are to improve the understanding of hydrogeochemical interactions between oxidized waste rock and shallow water covers, and to improve AMD prediction techniques by characterizing physical and chemical processes taking place in a waste rock pile.

**Status:**

Waste rock is commonly stockpiled near open pit mines and acid generation has occurred in waste rock stockpiles at a number of sites. Disposal of oxidized waste rock in a flooded open pit is a potential long term control option, but could potentially result in the mobilization of soluble oxidation products. An assessment of the technical and economic feasibility of backfilling a flooded open pit with oxidized material must therefore consider the long term evolution of surface and groundwater quality and requirements for active treatment prior to abandonment.

The objectives of the original work plan were to evaluate the effectiveness and operating costs to place oxidized waste rock in a flooded open pit, treat pit water by lime neutralization and cover exposed mineralization in the pit walls. The project was to include laboratory evaluation of contaminant leaching and water treatment requirements, prediction of surface and groundwater quality and a large scale field trial using the N5 open pit. The site is well suited for such a trial as baseline hydrogeochemical data is available and waste rock was removed to stockpiles near the Stratmat open pit.

The project originally consisted of both a field and laboratory component running concurrently. The scope of the project was reduced to exclude significant field work. The new work plan concentrated more on the laboratory component (data compilation, field sampling of the various materials and a laboratory program).

Given the change in scope, MEND is currently reviewing the project's status and the reviews have been favourable.

## *TREATMENT*

**Project 3.14.1:** Evaluation of Passive Systems for Treatment of AMD
Budget: $60,000
Sponsors: .................................................................. CANMET $60,000
Manager: Geneviève Béchard
Contractor: Kilborn

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### Objectives:

This project will complete a review and evaluation of passive treatment systems, identify the critical design criteria and operating parameters, provide an estimate of costs for treatment of AMD using passive systems and make recommendations on their applicability in Canada.

### Status

The contractor has reviewed and summarized the available information on passive treatment systems, particularly those methods using biotechnology. Considerable research and process development has been done on passive systems for treatment of AMD, particularly in the United States. In Canada, through the MEND Program, a considerable amount of resources has been allocated to projects related to passive treatment options.

The performance and the applicability of these systems has been reviewed and several process-limiting factors, such as temperature, flow rates, and rates of addition of bacteria nutrients, have been identified.

A draft report has been received, but the contractor has not yet met the full terms of reference in extending the information into applications at metal mine sites in Canada. It was an important objective of this study that the identification of conditions of application and recommendation on applicability of passive treatment systems in Canada be completed. Also, an analysis of capital and operating costs required for the passive treatment of AMD is still to be completed.

It is expected that an acceptable final report will be available by August 1995.

## *TREATMENT*

**Project 3.21.1b:** Removal of Metals from AMD - Ion Exchange
Budget: $64,000
Sponsors: .......................................................................... Teck
$10,000
Falconbridge .............................................. $ 4,000
Ontario ..................................................... $30,000
Homestake ................................................ $20,000
Expenditures: $17,000
Manager: T. Hynes, CANMET
Contractor: CANMET

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**Objective:**
Assess and demonstrate the applicability of ion exchange to remove selected metals from acidic drainage.

**Status:**
The extraction of metals from acid mine drainage solutions using selected ion exchangers was studied in batch and column tests using synthetic solutions. The tests were carried out at low, at mildly acidic, and at neutral pH.

The ion exchange extraction of metals from acid mine drainage was shown to be possible, but the extraction efficiency varied widely. Copper and antimony can be extracted with relatively good selectivity, even at low pH. Copper presents good prospects for recovery, but more tests would be needed to address the problems associated with slow adsorption kinetics and co-extraction of iron. The extraction of Cd, Ni and Zn is feasible under mildly acidic or neutral pH with moderate efficiency.

The bulk extraction of Cd, Ni and Zn at neutral pH is feasible with either a chelating resin or a synthetic zeolite. Preliminary calculations indicate that the ion exchange alternative may be economically advantageous, especially if zeolites are used.

Ion exchange resins show potential for lowering the metal content of treatment sludges produced downstream. This could provide a low maintenance scenario at a site where acidic drainage has ceased, and the lime treatment plant is shut off.

Additional experiments are now in progress with an actual acid mine drainage solution. Early results indicate that the extraction of copper, antimony and zinc are technically feasible from the solution. The recovery of zinc requires a partial neutralization to pH 4.5 to eliminate ferric iron from the solution. It is believed that further neutralization to pH 10, as is common practice, may be not necessary after ion exchange. This would represent a significant reduction in lime consumption and in the toxicity of the neutralization sludge.

Further work is aiming at obtaining additional data and to address the economical and ecological aspects of the lime neutralization, with and without ion exchange.

| | |
|---|---|
| **Project 3.31:** | Use of Lime Sludges for Capping |
| Budget: | $30,000 |
| Sponsor: | INCO $6,700 |
| | CANMET $23,300 |
| Expenditures: | $12,000 |
| Manager: | P. Kondos, CANMET |
| Contractor: | Laurentian University |

**Objective:**

The main objective of this project was the examination of modified lime sludge as a capping material for waste rock or tailings.

**Status:**

Inorganic materials when used for capping are susceptible to failure in providing water-tight and air-tight capping because of cracking as the rock or tailings pile settles, or because of desiccation. In this work, it had been proposed that lime sludge be used as a filler in an inexpensive elastomeric material which in turn would be used as a capping cement. An elastomeric cement was to be designed which would contain a large proportion of sludge in its matrix. Investigation of the compatibility of the treatment plant sludge with elastomer would be undertaken and sludge modification undertaken if required.

In 1993, mine sludge was characterized with respect to its components and interaction with water. Some solid phases of the sludge were identified. A number of elastomeric compounds were tested as possible matrix material for sludge solids at various sludge loadings.

It was determined that wet sludge solids (86% solids) can be blended with a number of elastomeric materials. The next steps were to:

- determine the adhesion characteristics of capping material to typical waste rock; and

- evaluate the effect of adverse conditions on elastomeric material.

**PROJECT WRAP-UP:**

Unfortunately, the principal investigator, Dr. W. Pacika, died in 1994. Laurentian University has undertaken to have the interim results written up for presentation to the project funders and to MEND by March 1995. No additional experimental work is planned.

**Project 3.41.1a**: In Situ Treatment of AMD
Budget: $41,000
Sponsor: ................................................................ Falconbridge
$11,000
MOEE.................................................. $30,000
Expenditures: $41,000
Manager: D. Abbott, MOEE
Contractor: David Blowes, University of Waterloo

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**Objectives:**

To develop and test the use of permeable reactive walls for the subsurface treatment of drainage waters derived from sulphide-bearing mine-tailings impoundments and to demonstrate the use of this technology on a pilot scale in the field.

**Status:**

The first year of this study (Phase I) dealt with the theoretical and laboratory assessment of reactive mixtures potentially suitable for treatment of drainage waters associated with inactive mines wastes. A variety of reactive materials were studied. Selection of an optimum material for field testing was made along with development of fundamental characteristics, porosity, and permeability required for solute-transport modelling.

A test cell placed in a plume of tailings-derived groundwater at a nickel mine was able to reduce sulphate concentrations from 3500 mg/l to 7 mg/l, iron from 1000 to <5 mg/l, and nickel from 2 to <0.01 mg/l. Early indications are that 5 to 10 years of life can be expected from these permeable reactive walls.

## *TREATMENT*

Such a system may have an important role to play in treating contaminated water plumes at acid-generating waste sites.

## TECHNOLOGY TRANSFER

**Project 5.2.1a-d**: Communications Plan - CIMM Lectures, Brochure, TV Series
Budget: $155,000
Sponsors: CANMET $80,000
Ontario $75,000
Expenditures: $132,000
Manager: G. Feasby
Contractors: In house, CANMET Secretariat (brochure, CIMM lectures), Topek (video)

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**Objectives:**
To inform key audiences about the issue of acidic drainage and the new affordable technologies being developed to solve the problem, and about MEND as a cooperative initiative involving governments and industry working together towards practicable, affordable solutions.

**Status:**
In 1993, the Communications Task Force appointed by the Board of Directors recommended that a communication expert be hired to aid in implementing the proposed communications strategy.

A Communications Workshop was held in June 1993 to identify MEND business strategies, targeted audiences, communications strategies and communications vehicles. The following strategies were recommended, and *in 1994 action was taken*:

- The CIMM Distinguished Lecturers Series. *Louis Sirois was nominated, a presentation prepared and delivered to 6 local CIMM Branches. More are planned in 1995;*
- A print brochure to convey basic information about AMD and the technologies being developed to solve the problem. *Complete;*
- A series of television programs on the Mining Industry, prepared by the Mining Association of Canada and ISTC. *This was not attempted because of cost, possible duplication of programs produced by others, and by the MEND video;* and
- A video on MEND and control of acid mine drainage. *This is in progress. A long (20 minutes)*, "technical" video has been produced in

*TECHNOLOGY TRANSFER*

English and French versions, and a short (12 minute) "general public" version will be available in May 1995.

Five thousand copies of the brochure on MEND have been produced and they will be widely distributed - with the MEND newsletter, at conferences and workshops. The long version of the video will be targeted to the mining industry and to government agencies, the short to libraries, schools and television stations. Copies of both versions will be sent to selected groups outside Canada.

**Project 5.7.1**: MEND Newsletter
Budget: $3,000
Sponsors: .................................................................. CANMET $3,000
Expenditures: $4,500
Manager: G. Feasby
Contractor: In-House, MEND Secretariat

**Objective:**

To keep MEND Participants informed of progress on current efforts to find workable and economic solutions to the significant environmental liability posed by Acid Mine Drainage.

**Status:**

To ensure that the objectives of MEND are achieved, results of the research work on acidic drainage have to be transferred to users. Regular publication of a Newsletter is an effective way to inform MEND participants on research progress. It also promotes communication among members and advertises the existence and purpose of the MEND program.

Two issues have been published and distributed to over 600 people in 1993, and expanded to 900 addresses in 1994. Information was given on technical projects in the area of Prevention & Control and Monitoring, people involved in the Program, recent publications, upcoming events, and special features on how MEND operates. Workshops held in 1993 and 1994 were featured.

## *TECHNOLOGY TRANSFER*

The Newsletter will continue to be published in 1995 and the distribution will be expanded (other than by mail).

## NEW IDEAS & INNOVATION

**Project 6.2**: New Ideas Solicitation - Round 2
Budget: $95,000
Sponsors: ........ CANMET
$30,000
Cape Breton Development Corporation ........ $10,000
Québec ........ $20,000
Environment Canada ........ $10,000
Ontario ........ $25,000
Expenditures: $89,400
Facilitator: K. Wheeland
Contractors: Various

### Objectives:

The New Ideas Task Force solicited new ideas and innovation that would provide technology to significantly reduce the cost of preventing, controlling and treating acid mine drainage.

### Status:

Table 19: Summary of Round 2 - Project Status/Results

| Project | | Researcher | Results |
|---|---|---|---|
| #14 | Froth Flotation, Lit. Review | Noranda | Japanese test results look relevant |
| #15 | Creation of a Limestone Precipitate Layer in Coal Waste | ADI Nolan Davis | Shows poor results |
| #16 | Ion Flotation for Zn | Laurentian University with Japanese collaboration | Active - to test strong AMD "cocktail" with lime as pH control |
| #20 | Polyurethane Covers | Queen's University | Cost about $17/m2 |
| #21 | Modified Clay Cover | Alta Res. Council | Initial blend successful but expensive |
| #22 | Selective IX Resins | McGill University | Rigorous tests indicated poor selectivity |

| Number | Titles |
|---|---|
| 1.16.3 | Critical Evaluation of Procedures to Determine the Potential of Mining Wastes to Produce Acid Rock Drainage |
| 1.16.4 | Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data for Selected Mine Sites |
| 1.16.5 | Identification of Qualitative Factors in Standard Static Prediction Test Protocols |
| 1.18.1a | Development of an Information System to Assist with the Interpretation of Static Acid-Base-Accounting Test Data |
| 1.27.1a | Guide for Predicting Water Chemistry from Waste Rock Dumps - Phase I |
| 1.41.3a | Waste Rock Pile Monitoring Ontario - Phase I |
| 1.41.3b | Waste Rock Pile Monitoring Ontario - Phase II |
| 1.41.4 | Waste Rock Pile Monitoring - Low Acid Production (Borderline) |
| 1.44.1 | Waste Rock Pile Disassembly - B.C. |
| 1.61.1 | Permafrost - Technical Review |
| 1.61.2a | Acid Rock Drainage (ARD) Prevention and Control: Towards a Tailings and Waste Rock Strategy for Using Permafrost to Manage ARD |
| 1.61.2b | Permafrost - Cullaton Lake Data Analyses and Interpretation |
| 2.11.1e | Peer Review on the Subaqueous Disposal of Tailings - Phase II |
| 2.11.5b | Shallow Water Covers - Equity Silver (Phase II) |
| 2.12.1b | Man-made Lakes Disposal Sites - Louvicourt Project |
| 2.15.2 | Metal Releases after Flooding |
| 2.17.1 | A Review of the use of an Elevated Water Table as a Method to Control and Reduce Acidic Drainage in Tailings |
| 2.21.3 | Peer Review of Waite Amulet and Heath Steele Soil Covers |
| 2.22.2b | Evaluation of Dry Covers Built from Mine Tailings - Field |
| 2.23.3b | Design Parameters - Pervious Envelope and Porous Surround Methods |
| 2.25.3 | Assessment of Alternate Materials for Dry Covers for Reducing Acid Generation from the Strathcona Tailings |
| 2.31.1c | Additional Monitoring of the Composite Cover at Heath Steele |
| 2.36.3 | Review of Methods for Characterization of Waste Rock Prior to Underwater Disposal |
| 2.37.1 | Layering Different Types of Waste Rock to Create a Non-acid Generating Composite - Case Studies |
| 2.37.2 | Review of Methods for Delaying Onset of Acidic Drainage - Case Studies |

| | |
|---|---|
| 2.37.3 | Characterization of Test Materials from Samatosum Column Study |
| 3.41.2 | Metal and Sulphide Surface Biomineralization |
| 3.42.2 | Lime Sludge Stabilization, Disposal and Use |

| Number | Titles |
|---|---|
| 4.5.4 | Environmental Monitoring Handbook for Acid Mine Drainage |
| 4.6.5a | Demonstration of a Field Method to Determine the Oxygen Flux Across the Surface of Tailings |
| 4.6.5b | Demonstration of a Field Method to Determine the Oxygen Flux Across the Surface of Waste Rock |
| 5.1.2 | Workshops |
| 5.6.3 | Fourth International Conference on the Abatement of Acid Rock Drainage |
| 5.7.2 | CD ROM Publication |

***PREDICTION*** ***Chemical Prediction***

**Project 1.16.3**: Critical Evaluation of Procedures to Determine the Potential of Mining Wastes to Produce Acid Rock Drainage

Budget: $30,000

Sponsors: ..........................................................................................

Environment Canada

..................................................................................................... $20,000

HBMS ....................................................... $10,000

Manager: B. Godin, Environment Canada

Contractor: University of British Columbia

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**Objectives:**

To conduct a rigorous evaluation of the range of application and shortcomings of static prediction procedures, principally the standard acid-base accounting test, currently used by the Canadian mining industry and regulators to facilitate mining waste management and permitting decisions. Also, to provide recommendations for the use of static test procedures and their interpretation for acid rock drainage prediction to assist in the prevention or reduction of pollution to receiving waters.

**Fit With Program:**

The ability to provide a comprehensive, scientific, technical and economic basis to predict with confidence the long-term management requirements for reactive mine wastes is one of the main objectives of the MEND program.

The short and long-term effects of acidic drainage, specifically from reactive waste rock at mine sites has become a serious concern. Current methods to determine neutralization potential (NP) are subject to extremes in variability causing great ambiguity in determined NP and calculated NNP values. The objective of the proposed work is to simplify the existing acid-base accounting procedures by taking into account readily available alkalinity, total alkalinity and mineralogy of the samples.

**Projected Output:**

This project will produce an in-depth assessment of currently used static test procedures and recommendations as to the interpretation of data resulting from these tests. A description of the importance of mineralogy when considering total available alkalinity and calculating long-term buffering capacity of acid rock will also be given.

The results will be of significant value to mining companies and regulators alike when considering effective waste management strategies.

***PREDICTION*** ***Chemical Prediction***

**Project 1.16.4**: Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data for Selected Mine Sites

Budget: $27,200

Sponsors:

| | |
|---|---|
| Gibralter Mines Ltd. | $6,800 |
| Placer Dome Canada Ltd. | $4,000 |
| Cominco Ltd. | $3,400 |
| Teck Corporation | $7,000 |

Manager: To Be Determined

Contractor: University of British Columbia

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**Objectives:**

The objectives of this project are 5-fold and include: determine the ability of static and kinetic prediction techniques to identify on-site conditions; investigate the relationship between static prediction parameters and lithogeochemistry; identify the processes and reactions that affect both laboratory and field kinetic tests and compare laboratory and field determined rates of metal release and water quality trends; investigate the relation between static prediction parameters and kinetic (field and laboratory) information; and provide a review of the current interpretative and reporting methodology used to assess ARD prediction data. This will include an assessment of criteria for waste management objectives currently used and proposed by regulators.

**Fit with Program:**

Acid rock drainage remains a major challenge and obstacle to providing long term environmental protection and reclamation of land at mine sites. In order to satisfy environmental protection regulatory requirements, laboratory and on-site investigations include waste characterization to assess ARD potential, and baseline and ongoing environmental studies. These data allow proponents of new mines and operators of existing mines to complete waste management plans that would prevent or mitigate the generation of ARD and the migration of contaminated runoff both during operation and long after closure. Waste characterization methods via either static or kinetic methods are limited due to a number of limiting assumptions made or to the inability to provide long-term projections of the potential for a material to generate ARD. This project will incorporate available static and kinetic prediction data and field monitoring data from selected mine sites to determine how the current prediction techniques approximate observed ARD conditions on-site.

**Projected Outputs:**

An in-depth assessment of the value of currently used tests and methods of interpretation to predict ARD characteristics of mine wastes will be completed. The results will be of significant value to mining companies and regulators alike when considering effective waste management strategies.

***PREDICTION*** ***Chemical Prediction***

| | |
|---|---|
| **Project 1.16.5**: | Identification of Qualitative Factors in Standard Static Prediction Test Protocols |
| Budget: | $50,000 |
| Sponsor(s) | To Be Determined |
| Manager: | To Be Determined |
| Contractor: | Competitive Bid |

**Objectives:**

The prime objective is to define the qualitative factors incorporated into currently popular static test methods. This will lead into the second, more critical objective, of developing a rigorous analytical protocol suitable for interlaboratory test programs aimed at developing certified reference materials.

**Fit With Program:**

A previous project (1.16.2a) was designed to prepare a certified reference material (CRM) for static test methods. A CRM is useful to compare NNP for protocol assessment, development, laboratory comparison or quality control. However, only provisional values for NNP could be stated due to a number of problems primarily related to the test methodology. These methods usually contain qualitative components which tend to decrease the accuracy and precision of any analytical information derived from the results of these tests. Clearly, the ambiguous portions of the methodologies must be identified and either removed or improved.

The Sobek method is the method of choice for this study as it is one of the most commonly employed in the Canadian mining industry. Also, since it was the method used in the NBM-1 interlaboratory study (1.16.2a), a direct comparison of the results obtained with the current Sobek method and those that would be obtained with a quantitative Sobek method can be achieved.

The defined analytical protocol would not be intended to be a standard method for ABA testing but rather a basis from which a greater understanding of these techniques may be developed.

**Projected Output:**

A rigorous analytical protocol will be defined that does not contain qualitative components normally found in static test procedures. This will lead to an increase in the precision of interlaboratory test methods, and ultimately lead to CRM development.

***PREDICTION*** ***Chemical Prediction***

**Project 1.18.1a:** Development of an Information System to Assist with the Interpretation of Static Acid-Base-Accounting Test Data

| | |
|---|---|
| Budget: | $50,000 |
| Sponsor(s): | To Be Determined |
| Manager: | To Be Determined |
| Contractor: | Competitive Bid |

**Objective:**

The specific objective of the proposed work is to develop a simple information system to facilitate the analysis of acid-base-accounting (ABA) test data. The system should take into account ABA, chemical and mineralogical data as a minimum and recommend to operators the necessary steps required to minimize the risk associated with ARD.

**Fit With Program:**

The ability to provide a comprehensive, scientific, technical and economic basis to predict with confidence the long-term management requirements for reactive mine waste is one of the main objectives of the MEND program.

The short and long-term effects of acidic drainage, specifically from reactive waste rock at mine sites is a serious concern. Current methods to determine neutralization potential (NP) are subject to extremes in variability causing great ambiguity in determined NP and calculated net neutralizing potential (NNP) values. These ambiguities lead to extreme difficulty in the interpretation of the results of ABA test data and potentially incorrect conclusions regarding the potential for the material to be acid generating.

The proposed work is meant to simplify the interpretation of existing ABA procedures by the use of an information system to analyze all data relevant to ABA (NP, mineralogical, chemical analytical etc.). The system should take a step-wise approach where operators are informed of the uncertainty at each step with the amount of data available and recommendations to reduce the uncertainty are given to the operator. The information system is not meant to be a predictive model nor would it be used for decision making but rather as a tool for data analysis.

**Projected Output:**

The principle output will be a user-friendly information system to interpret the results of typical ABA static test results in conjunction with other analytical data.

***PREDICTION*** ***Modelling***

**Project 1.27.1a:** Guide for Predicting Water Chemistry from Waste Rock Dumps-Phase I

Budget: $35,000

Sponsor: ........................................................................ CANMET $35,000

Manager: C. Weatherell, CANMET

Contractor: Norecol, Dames and Moore (by competitive bid)

### Objective:

The objective of this project is to consider the empirical approach to complement the existing deterministic models used for predicting geochemical parameters in existing waste rock dumps.

### Fit With Program:

A number of alternatives for predicting response characterizations from waste rock dumps are being investigated. One approach is to characterize seepage with the expectation of determining the potential future behaviour of the waste rock pile and the behaviour of different waste rock dumps with a similar composition.

Seepage characterization has been applied at three sites in western Canada and three sites in eastern Canada. This work involved a compilation of all water chemistry at a site into one database and the creation of scatter plots of one water chemistry parameter against another. The resulting scatter plots revealed surrogates, typically pH or sulphate, from which all other parameters could be estimated within definable error bars around a mean best-fit-line.

The case studies put forth for the current work will independently verify the applicability of this approach. Other statistically sound mathematical techniques will also be applied to further verify the applicability of an empirical approach.

### Projected Output:

The validity of the documented empirical approach will be tested to determine whether realistic predictions of seepages from waste rock piles can be determined from existing, historical data. The validity of mechanistic interpretation of the empirical results will also be verified. Alternative methods for sound statistical analysis of waste rock seepage data will be recommended.

***PREDICTION*** ***Waste Rock Knowledge***

**Project 1.41.3a**: Waste Rock Pile Monitoring Ontario - Phase I
Budget: $30,000
Sponsors: ................................................................... CANMET
$15,000
Ontario ................................................. $15,000
Manager: C. Weatherell, CANMET
Contractor: Trow Consulting Engineers Ltd.

**Objective:**
The objective of this project is to develop a workplan to provide the detailed laboratory and field programs, data analyses, data interpretation and exact costs, for an extensive 2-year monitoring program for the waste rock pile at the Whistle Mine in Sudbury.

**Fit with Program:**
The development of useful predictive techniques for masses of acid generating waste rock depends on a thorough understanding of the basic principles involved. Other factors such as: mineral composition, size distribution, location, deposition method and history and climate must also be thoroughly understood.

In Canada, the primary concern about sulphide-containing waste rock deposits is that of water quality, principally resulting from the contamination of surface infiltration. Water quality at several waste rock dumps in Canada is being monitored including at: Cape Breton, N.S.; Heath Steel, N.B.; Mine Doyon, Qué; and Island Copper, Myra Falls, Mount Washington, B.C. Information from these dumps is providing useful information for a database of rock pile effluent monitoring. However, except for Mine Doyon, acid-generating rock pile behaviour is not well documented in Canada. Further information is therefore required on the physical and chemical behaviour of acid generating rock piles.

The waste rock pile at the Whistle mine near Sudbury, Ontario is a good candidate site for this project for various reasons. The site is new (~14 years old); it is relatively small in size (3M tonnes); sampling wells for water quality monitoring have been initiated outside the pile; surveys have been conducted on this site including EM-31; the site is not affected by local metallurgical operations; the pile mineralogy represents many other base metal rock piles; and the mine owner will co-operate fully to ensure the successful completion of this project.

**Projected Output:**

A detailed workplan for the implementation of a 2 year monitoring program for a waste rock pile will be prepared. The plan will be designed for application to other waste rock piles that may require monitoring in the future.

***PREDICTION*** ***Waste Rock Knowledge***

**Project 1.41.3b:** Waste Rock Pile Monitoring Ontario - Phase II
Budget: $305,000
Sponsors: ........................................................................ CANMET $115,000
Ontario ........................................................ $115,000
Manager: C. Weatherell, CANMET
Contractor: To Be determined

**Objectives:**

The primary objective of this project is to obtain a healthy database of waste rock information that can be correlated to existing rock pile information to assist the understanding of the future behaviour of waste rock piles with an emphasis on predictive modelling. Also, the effectiveness of the Waste Rock Sampling Manual developed by MEND (4.5.1b) will be assessed.

**Fit With Program:**

The development of useful predictive techniques for masses of acid generating waste rock depends on a thorough understanding of the basic principles involved. Other factors such as: mineral composition, size distribution, location, deposition method and history and climate must also be thoroughly understood.

In Canada, the primary concern about sulphide-containing waste rock deposits is that of water quality, principally resulting from the contamination of surface infiltration. Water quality at several waste rock dumps in Canada is being monitored including at: Cape Breton, N.S.; Heath Steel, N.B.; Mine Doyon, Qué; and Island Copper, Myra Falls, Mount Washington, B.C. Information from these dumps is providing useful information for a database of rock pile effluent monitoring. However, except for Mine Doyon, acid-generating rock pile behaviour is not well documented. Further information is therefore required on the physical and chemical behaviour of acid generating rock piles.

**Projected Output:**

The primary product of this project is a healthy database of waste rock information and an enhanced understanding of the principles and mechanisms of acid rock drainage production. The applicability of deterministic and empirical models to the data will be determined as will the demonstration of application of the Waste Rock Sampling Manual developed by MEND (4.5.1b).

***PREDICTION*** ***Waste Rock Knowledge***

**Project 1.41.4**: Waste Rock Pile Monitoring - Low Acid Production (Borderline)
Budget: $200,000
Sponsor(s): To Be Determined..............................................$200,000
Manager: To Be Determined
Contractor: To Be Determined

**Objective:**

The primary objective of this project is to obtain fundamental information from a waste rock pile that has either not yet produced acid, or has been predicted to not be acid generating but is now showing signs of sulphide oxidation.

**Fit With Program:**

The development of useful predictive techniques for masses of acid generating waste rock depends on a thorough understanding of the basic chemistry and physics of these piles. Since these waste piles are often not similar in composition, mineralogy, size, size distribution, location, history etc., the fundamental characteristics of each will differ. This leads to varying behaviours with respect to acidic drainage quality and flux.

In order to ensure accurate predictions of future waste rock pile behaviour, the fundamental characteristics of several types of waste rock piles must be well documented and thoroughly understood. The Mine Doyon project represented one waste rock pile while the proposed monitoring of the Whistle site represents another. A third type, namely a low acid production pile, is proposed to gain insight as to the mechanisms responsible for the low flux of acidic drainage produced.

This project will rely on the experience from past and current projects and on the Waste Rock Sampling Manual (4.5.1b).

**Projected Output:**

The primary product of this project is a major contribution to the existing and currently developing database of waste rock information. An enhanced understanding of the principles and mechanisms of acid rock drainage production will be gleaned. The applicability of deterministic and empirical models to the data will be determined in the context of waste rock piles that are not heavy producers of acidic drainage. The utility of the Waste Rock Sampling Manual developed by MEND (4.5.1b) will also be assessed.

***PREDICTION*** ***Waste Rock Knowledge***

**Project 1.44.1**: Waste Rock Pile Disassembly - B.C.
Budget: $30,000
Sponsor: Homestake Canada
$35,000
Manager: W. Napier, Homestake Canada
Contractor: Morwijk Enterprises

### Objective:

The specific objective of the proposed work is to provide qualitative and quantitative information on mass transport and water infiltration within a waste rock pile.

### Fit With Program:

The prediction of water chemistry depends in part on the movement of water through waste rock. Waste rock pile hydrology is determined by processes and factors including: precipitation, annual and event runoff, evapotranspiration, dumping practices, infiltration, saturated flow rates, gas flow and topography. Waste rock pile hydrology is poorly understood partly because of the scarcity of available data and partly because of gaps in the fundamental knowledge in the areas of chemical and hydrological processes. The methods and patterns of water movement through waste rock piles can be used as an indicator of the complexity of developing coupled geochemical-hydrological predictive models.

Although there are some lysimeter tests described in the literature that provide information on mass transport and infiltration, there is little documentation describing the hydrogeology within an actual waste rock pile as confirmed by observations taken during the disassembly of a rock pile. Only one such study has been identified. A relatively small waste rock pile (70,000 tonnes) in British Columbia will be disassembled and moved to a subaqueous storage site during the spring of 1995, affording an excellent opportunity for this work.

### Projected Output:

Still photographs and video recordings of the waste rock dump during disassembly showing relevant features of water transport (via staining) secondary mineral deposits, where applicable will be provided. Secondary mineral products obtained from inside the waste rock dump during disassembly will be identified. A final report detailing all qualitative and quantitative results obtained throughout the project including: secondary mineral formation in the waste rock pile; observations pertinent to mass transport and water infiltration observed during the test work and disassembly of the waste rock pile; and finally conclusions as to the mechanisms of mass transport and water infiltration in the waste rock pile.

***PREDICTION*** ***Permafrost***

**Project 1.61.1**: Permafrost - Technical Review
Budget: $32,000
Sponsor: ........................................................................ DIAND $32,000
Manager: M. Barnett, DIAND
Contractor: CANMET

**Objectives:**
The objective of this work is to present a summary report of information, data, and critical parameters in two primary areas. These areas are:

- the role that ice and snow cover plays in the water cover option for the disposal of reactive tailings, and
- the role of permafrost in the long-term management of acid generating tailings.

**Fit With Program:**
There is a wealth of literature on the characteristics of ice covers and permafrost and their potential impact on tailings waste management in the north.

This review and assessment will provide a basis upon which to consider the design and implementation of laboratory and field studies to evaluate the effects of ice on water covers. An evaluation of the use of permafrost as a dry cover by freezing tailings permanently will also be included. Brief overviews of the climatic conditions in northern Canada and the associated level of mining activity in the Yukon and Northwest Territories will be presented. The application of wet and dry barriers as control technologies will be discussed in the context of assessing the impact of northern conditions on the water cover option, and the impact of permafrost as a dry barrier on tailings reactivity. The role of ice and water cover will be reviewed with considerations to: risks to structures and barriers; the potential impact of ice scouring on material disposed sub-aqueously; the potential thickness of ice covers; snow fences; and the role of snow removal versus accumulation to ice thickness.

The impact of permafrost, specifically on the freezing of sulphide bearing mine wastes, will be addressed in depth. The characteristics of continuous and discontinuous permafrost will be introduced. The impact of in situ temperatures, hydrology, and permeability on chemical and bacterial activity is further developed. The characteristics of the active freeze-thaw layer will be addressed as will the methods for promoting permafrost.

**Projected Output:**
This project will result in a concise compendium of currently available permafrost knowledge that may be employed for developing mine waste management strategies for northern climates.

*PREDICTION* *Permafrost*

**Project 1.61.2a**: Acid Rock Drainage (ARD) Prevention and Control: Towards a Tailings and Waste Rock Strategy for Using Permafrost to Manage ARD.

Budget: $50,000

Sponsor: ........................................................................ DIAND $50,000

Manager: M. Barnett, DIAND

Contractor: To Be Determined

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**Objectives:**

The objective is to review and report on the circumpolar permafrost technology experience as a control mechanism for northern mines, including available kinetic data; to design and report a generic 2-3 year field program for tailings and waste rock, including parameters to be monitored and their frequency.

**Fit With Program:**

The prediction and management of acidic drainage from mine wastes constitutes a major undertaking because of intrinsic heterogeneities, the elementary level of present capabilities, and the lack of abundant, precise field data. Prediction of acidic drainage potential at northern mines is complicated because of the interpretation required to account for the climatic regime with extreme temperatures. Further research is needed for the development of reliable laboratory predictive methods for northern conditions and field evaluations are essential.

Acid-base accounting is the first acid generation predictive testwork conducted by most mining companies to classify waste rock and tailings. The maximum ARD production potential of a sulphide sample will not change, however, the rate of generation and release will be generally reduced by low temperatures. In terms of mining, the reduced rate is crucial in that the surrounding environment is more able to assimilate, dilute or neutralize the chemical input due to the longer timeframe. Unfortunately, a 'standard test' may not recognize this advantage.

The literature suggests that low temperature conditions slow both geochemical and biochemical oxidation processes associated with sulphide minerals. There is a need to carefully examine these findings in the field and maximize any benefits that may arise.

**Projected Output:**

The primary product will be a design for operating criteria for cold mine wastes. Secondly, a documented, generic field program to test the design and provide a sampling protocol and frequency running until 1997 will be provided. Recommended responses to be evaluated in the event that the resulting data differ from predicted responses will also be included.

***PREDICTION*** ***Permafrost***

**Project 1.61.2b**: Permafrost - Cullaton Lake Data Analyses and Interpretation
Budget: $10,000
Sponsor: ............................................................................Homestake $10,000
Manager: W. Napier, Homestake
Contractor: To Be Determined

**Objectives:**

To provide insights into the oxidation and leaching characteristics of mine tailings and the activity of bacteria at low temperatures.

**Fit With Program:**

Column leaching tests to evaluate the kinetic oxidation potential and leaching characteristics of tailings from the Cullaton Lake Gold Mines in the Northwest Territories at room temperature and under simulated cold conditions have been conducted for almost 2 years. A wealth of information has been generated that requires intensive review, interpretation and presentation in a concise format. Part of the mandate of the Permafrost program area is to determine the effect of temperature on the leaching characteristics of mine tailings. In this fashion the effect of acidic drainage in cold climates on the environment can be addressed more accurately. Also, the reduced ability of bacteria to assist with the oxidation of mine wastes will be verified.

**Projected Output:**

The data will assist in determining the influence of temperature on the leaching characteristics of mine tailings.

## *PREVENTION AND CONTROL -Underwater Disposal*

**Project 2.11.1e**: Peer Review on the Subaqueous Disposal of Tailings - Phase II
Budget: $30,000
Sponsor: .............................................................. CANMET $30,000
Manager: W. Fraser, Hudson Bay Mining and Smelting
Contractor: Resources Futures International

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**Objective:**
Scientific and regulatory review and planning is a major part of the program, and is assisting in achieving a fair and objective study of the concept and methodology for subaqueous disposal of reactive tailings in lake. The objective of this project is to assess the work undertaken over the past three years in context with the original points of concerns identified in the first peer review (2.11.1d).

**Fit with Program:**
In 1991, at the invitation of MEND, the Rawson Academy of Aquatic Science completed a first peer review on subaqueous disposal. A final report " A Critical Review of MEND Studies Conducted to 1991 on Subaqueous Disposal of Tailings" was submitted in July 1992 (2.11.1d). Recommendations made in the peer review formed the basis of geochemical field studies which were carried out in Anderson Lake (2.11.3) and Buttle Lake (2.11.4).

It is now appropriate to assess the work undertaken since the first peer review completed in 1992 and to address three main points:

1) How well have the MEND studies on Anderson and Buttle lakes met the recommendations and suggestions presented in the 1992 report;
2) What new insights have been derived from the 1992-95 field and laboratory studies on these two lakes, and what problems and concerns remain; and
3) What additional geochemical and other related studies are recommended to achieve the degree of certainty and credibility which will be needed to advance subaqueous disposal of tailings as an effective and environmentally acceptable technology for application by the mining industry.

**Projected Output:**
A strategy is needed to review the results of the studies. Elements were determined to include scientific peer review of completed and proposed work, government

regulatory agency review and final reports, and public review of the overall concept and scientific database. Although complex, it is as important to complete this review as was the technical study for the acceptance of this promising method of acid drainage control, and will continue over the entire program to the final objective of a design and application manual.

***PREVENTION AND CONTROL -Underwater Disposal***

**Project 2.11.5b**: Shallow Water Covers - Equity Silver (Phase II)
Budget: $80,000 to $195,000 (increase in scope)
Sponsor: ................................................................................
Placer Dome........................................................ $ 44,000
CANMET ..............................................$100,000
Manager: J. Robertson, Placer Dome
Contractor: To be determined

**Objective:**

The ultimate objective of the subaqueous disposal program is to establish a set of guidelines that can be employed during mine operation and following closure. Present conditions at the site will be examined and applicable physical and chemical variables reviewed to assist in the development of generic criteria for both operational mines and those undergoing closure.

**Fit with Program:**

The Equity Silver mine located near Houston, B.C. ceased operations in January 1994 and provides an excellent opportunity to investigate several of the physical variables associated with subaqueous disposal of mine tailings. Using the Equity Mine site to illustrate the dynamics of several of the key physical variables will lead to the start of the development of both operational and closure guidelines for subaqueous disposal of tailings. Phase I (2.11.5a), identified the critical physical parameters and reviewed the available information for these parameters. Phase II is a field program to supplement the existing information base in areas identified as being deficient to finalize the design criteria.

One of the findings of Phase I is that the geochemistry may be playing a more important role than originally thought. There is a need to clarify this assumption through a better understanding of the site and to accomplish this, a peeper program is proposed for 1995.

The proposed field program, other than the geochemistry component, will consist of the following: bathymetry of the tailings pond; sediment size analysis; ARD sampling and analysis; weather data; pond water quality (historically and current); and seasonal surveys of ice thickness and ice entrainment of fine particles.

**Projected Outputs:**

The Equity Silver tailings pond is one of the first sites to close that has used the concept of water covers over fresh tailings. It has both the desirable physical and chemical factors present thus allowing the development of general criteria based on experience.

### *PREVENTION AND CONTROL -Underwater Disposal*

| | | |
|---|---|---|
| **Project 2.12.1b**: | Man-made Lakes Disposal Sites - Louvicourt Project | |
| Budget: | $350,000 to $500,000 (increase in scope) | |
| Sponsors: | | |
| | CANMET | $342,000 |
| | Teck | $106,000 |
| | Aur Resources | $ 48,000 |
| Manager: | M. Filion, Teck | |
| Contractors: | Golder Associés/INRS-Eau/Noranda<br>CANMET/Aur Resources/SENES/UBC | |

**Objective:**
The objective of the field and laboratory project for the Louvicourt man-made lake tailings basin is to demonstrate the effectiveness of shallow water covers as a permanent means of preventing the oxidation of sulphide minerals and the consequent formation of acidic drainage.

**Fit with Program:**
Underwater disposal of mine wastes in man-made lakes is presently an option favoured by the mining industry to prevent the formation of acidic drainage. Because of the potential controversy associated with using natural lakes for subaqueous disposal, there is considerable interest in evaluating whether artificial basins offer similar advantages to natural lakes.

The project has been divided into three phases. The last phase will be completed after MEND has ended in 1997. Phase I, which cost $27k, was the conceptual design, costing and proposal formulation for phase II, the integrated laboratory and field studies ($469k est.). The phase II proposal, prepared by a group of experts following a one-day project definition session in Montréal in March 1994, was received in December.

A combination of laboratory experiments and two field test cells is proposed to achieve the objectives of the project. The laboratory column studies have been designed to assess shallow water covers (300 mm and 1 m to compare) in relation to flooded tailings covered with 300 mm of organic material. Two field test cell experiments have been designed: Cell #1 will simulate as nearly as possible conditions upon closure with a shallow 0.3 m of water; and Cell #2 will also simulate closure, but will incorporate wet organic material (0.3 m) along with a 0.3 m shallow water cover.

**Projected Outputs:**
Since flooding of mine tailings in artificial basins is the method preferred for new mining operations, the proposed study will lead to a better understanding of the factors involved in operating tailings basins in a man-made lake. Also the benefits of an additional layer of protective material in the water cover system will be assessed as part of the tool box of technologies being provided by MEND.

***PREVENTION AND CONTROL -Wet Barriers***

**Project 2.15.2:** Metal Releases after Flooding
Budget: $200,000
Sponsor: To be determined
Manager: R. Michelutti, Falconbridge
Contractor: To be determined

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**Objectives:**

The objectives of the project are to evaluate and characterize the short, medium and long term metal release rates to surface water and through seepage following flooding. Possible barrier materials that could be used to prevent upward fluxes to the surface cover will also be investigated.

**Fit with Program:**

Covering sulphitic mine tailings with water effectively reduces oxygen influx to the tailings and the resulting acid generation. However, metals present in porewater solutions or in soluble mineral phases may still be released from the flooded tailings impoundment. Results from a column experiment where oxidized tailings are covered by 1 m of water showed that transfer of zinc, sulphate, and iron from the tailings to the water column could occur. The transfer could be controlled by the addition of a protective sand layer over the tailings. Other barrier materials such as clean tailings and organic sediments may also prevent upward fluxes and should be investigated.

Metal types, concentration and loadings, as well as variations with time, have to be known to confidently evaluate the costs and benefits of using a water cover for decommissioning. For maximum environmental benefit, water covers should be applied as early as possible. This project will study the geochemical processes which influence the metal releases. One possible site to perform a field evaluation to evaluate the short, medium and long term metal release rates is Solbec Cupra where flooding has just begun.

**Projected Outputs:**

The construction costs for artificial hydraulic containment structures to obtain an adequate water storage over the tailings are always high. It is therefore recommended, before deciding to commit to these costs, to evaluate treatment and maintenance requirements using laboratory and field testing. This project will help define some of the costs associated with flooding of oxidized tailings.

***PREVENTION AND CONTROL -Wet Barriers***

**Project 2.17.1**: A Review of the use of an Elevated Water Table as a Method to Control and Reduce Acidic Drainage in Tailings
Budget: $50,000
Sponsors: ..........................................................................
Ontario ........................................................... $25,000
CANMET ............................................... $25,000
Manager: R. Michelutti, Falconbridge
Contractor: Competitive bidding

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**Objective:**

The objective of this project is to evaluate, technically and economically, the use of an elevated water table in sulphide-containing tailings to control and reduce acidic drainage.

**Fit with Program:**

Disposal options and the feasibility of using artificial methods to raise the phreatic surface above the reactive materials need to be evaluated technically and economically as a method of reducing acid production. If the fluctuating phreatic surface can be kept above the sulphides, this could provide a simple, economical abandonment strategy for the mining industry.

The primary goal of the project is obtaining an increased knowledge base with respect to the state-of-the-art for the option of creating an elevated water table to control acidic drainage. As a first step the contractor will review the basic geochemical principles of a wet zone and its purpose for controlling acidic drainage.

Three major activities are envisaged for the completion of this project. The first phase of the project will be the completion of an international literature review to identify actual cases and mechanisms where an elevated water table was or is being used. In the second phase, the contractor will be completing a review of physical (e.g. geotechnical) and geochemical parameters within the identified case histories that could have an effect on the concept of the elevated water table. The last phase of the project is a geotechnical and economic evaluation of possible scenarios that could be used to obtain an elevated water table.

**Projected Output:**

The key output is a discussion on the applicability of the elevated water table option with respect to geochemistry, geotechnical and economic considerations. A methods manual to evaluate the technical feasibility of the elevated water table for site specific applications will be included in the final report. The intent of the document is to allow operators to assess this close-out option for site specific applicability.

***PREVENTION AND CONTROL -Dry Barriers***

**Project 2.21.3**: Peer Review of Waite Amulet and Heath Steele Soil Covers
Budget: $50,000 to $70,000 (increase in scope)
Sponsors: ..........................................................................................
Cominco .............................................................. $47,000
CANMET ................................................ $17,000
Expenditures: $ 0
Manager: R. Gardiner, Cominco
Contractor: University of Saskatchewan

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**Objective:**
The objective of this increase in scope is to include in the scientific peer review several items of interest identified during the priority setting exercise. This will result in a more comprehensive peer review of covers in general.

**Status:**
Natural soil covers are a promising dry barrier for the control of acid generation in sulphide tailings and waste rock. There are a number of sites world-wide in which natural soil covers have been used. The design objectives of these sites vary; however, at most sites it is hoped that the presence of the cover will accomplish three functions:

- provide a low-hydraulic conductivity barrier to minimize the influx of water;
- provide an oxygen diffusion barrier to minimize the influx of oxygen; and
- provide a stable soil surface on which vegetation can be established.

The peer review will ensure the quality and completeness of the field data and interpretations which will provide the basis for the protocols and will enhance the scientific credibility of several key project reports. The review will also assist mine operators and regulators by increasing public confidence in the technical feasibility and cost of engineered soil covers.

A priority setting exercise was completed in early 1995 and several items were recommended for inclusion in the peer review. The following will be included:

- long term durability, including required maintenance and monitoring;
- non-mining soil covers;
- a review of cementitious covers, to wrap-up the study area; and
- a review of spray-on polyurethane membrane liners (this work was completed under the New Ideas Task Force).

**Projected Outputs:**
The deliverable for this project will be a report which will include a critical review of all project reports and the scientific literature related to material testing and the design, construction and monitoring of engineered covers. The report shall include specific recommendations concerning further research, monitoring or other work which may be necessary to validate the approach or to address any deficiencies which were identified.

***PREVENTION AND CONTROL -Dry Barriers***

| | | |
|---|---|---|
| **Project 2.22.2b**: | Evaluation of Dry Covers Built from Mine Tailings - Field | |
| Budget: | $200,000 | |
| Sponsors: | | |
| | Québec | $ 66,667 |
| | Itec Minéral inc. | $ 66,666 |
| | CANMET | $ 66,667 |
| Manager: | L. Bienvenu, Ministère des Ressources naturelles (MRN) du Québec | |
| Contractor: | École Polytechnique | |

**Objective:**
The objective of this study is to develop an alternative approach to cover design by using tailings in multilayer systems.

**Fit with Program:**
The objectives of the first phase (2.22.2a), which were to establish the calculation bases from laboratory experiments and numerical calculations, have shown that a capillary barrier can be created from non-reactive tailings. This layered system is effective to reduce the infiltration of water and to limit the diffusion of oxygen to a low enough level, thus preventing the generation of AMD from the sulphide materials underneath the cover. The specific objectives of the second phase are to study the performance of various cover configurations, on a large scale, to evaluate the actual behaviour of such systems exposed to realistic conditions, and to establish an optimum design procedure based on technical and financial aspects.

As per the instructions from the Management committee, a cost benefit analysis was required before considering this project. The use of the multilayer dry covers for tailings has potential for saving costs if more than one layer is constructed from tailings, and also if the materials are deposited hydraulically. In this project it is proposed that mechanical placement of the cover materials be used in the field thus reducing the economic benefit associated with the cost of placement.

After review it was proposed that the laboratory portion ($200k) of the project be accepted as full status. The field component, worth $400k, has been accepted as a MEND associate project. The project is fully funded, with each partner contributing $200k.

During the priority setting exercise completed in early 1995, it was recommended that laboratory protocols be developed to determine if the materials under consideration for use in covers have the physical properties that make an effective cover material. The laboratory portion will result in a rational design process that could be used at different locations when only basic information (e.g. grain size, mineralogy) is known.

**Projected Output:**
The main output from this project is a manual or set of laboratory protocols that the operator could use, that provides guidance for determining the potential effectiveness of the materials under consideration for use in a cover.

### *PREVENTION AND CONTROL - Others*

**Project 2.23.3b**: Design Parameters - Pervious Envelope and Porous Surround Methods
Budget: $25,000

Sponsor: ..........................................................................................
Ontario ............................................................... $ 25,000
Manager: M. Wiseman, Falconbridge
Contractor: To be determined

**Objective:**

The objective of this project is to evaluate the design parameters and basic principles needed to obtain a porous envelope effect. Both the natural porous surround (Falconbridge) and the engineered pervious envelope (Rabbit Lake) methods would be analyzed and key variables identified and modelled.

**Fit with Program:**

The porous surround/pervious envelope concepts are based on the fact that groundwater flow into low permeable tailings masses can be minimized if high permeable soils are placed adjacent to and surrounding the tailings. If differences between soil and tailings are sufficient, ground water penetration into the tailings mass will be eliminated or reduced to acceptable levels. Leaching of the tailings is then theoretically reduced to acceptable levels, creating a permanent, cost effective, maintenance free tailings abandonment strategy. An impermeable cover may or may not be required to further reduce surface water penetration and subsequent oxidation in the unsaturated zone. Two sites, one natural and one engineered, have conditions on site for porous surround/pervious envelope containment.

A recent MEND study (2.23.3) completed in 1994 has concluded that, based on field activities and computer flow modelling conducted over the past three years, conditions for porous envelope containment are occurring at the Falconbridge Fault Lake tailings site.

The engineered multilayer envelope system referred to as the "Pervious Surround Method" is being used at Rabbit Lake in northern Saskatchewan. Although conceived for use as a disposal method for uranium mill tailings, the concept is however considered to have potential applications for other wastes.

**Projected Outputs:**

The factors that contribute to create the effects outlined above are probably present at other locations near other mine sites. The final report will contain the necessary parameters and basic principles needed to obtain the porous effect, for both an engineered and natural systems.

## *PREVENTION AND CONTROL -Dry Barriers*

**Project 2.25.3**: Assessment of Alternate Materials for Dry Covers for Reducing Acid Generation from the Strathcona Tailings

Budget: $280,000

Sponsors:

| | |
|---|---|
| Falconbridge | $140,000 |
| Ontario | $ 70,000 |
| CANMET | $ 70,000 |

Manager: M. Wiseman, Falconbridge

Contractors: Lakefield Research/Falconbridge

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**Objective:**

The objective of this one-year pilot project is to investigate the use of various organic materials for covering tailings ponds. The effectiveness of various organic materials (e.g. peat, municipal solid waste compost and lime-stabilized sewage sludge) and one contrasting non-organic (desulphurized tailings) material on eliminating or reducing acid generation and the movement of acidity and heavy metals from tailings ponds will be investigated and compared to control plots.

**Fit with Program:**

Large quantities of organic material are now stockpiled, or may be available in the near future, from urban and industrial sources. The cities in Ontario are capable of producing approximately 680,000 tonnes of municipal solid waste (MSW) compost annually and create comparable amounts of sewage sludge, which is currently landfilled. These materials may provide effective and affordable solutions to the reclamation of acid generating mine tailings.

The organic layers to be investigated are believed to have physical and chemical characteristics that will decrease the rates of the acid generation processes in sulphide tailings or reverse the acid generation process and precipitate sulphides. These materials may also decrease the movement of water through the tailings pond. The organic materials to be studied are also potentially available in large quantities at low cost. In addition to organic materials, desulphurized tailings would be used as a contrasting non-organic cover layer that may be cost-efficient. The materials to be tested include a control, peat, lime-stabilized sewage sludge and desulphurized tailings with and without capillary barriers and compost. The need for and effectiveness of a capillary barrier to prevent vertical movement of dissolve materials in tailings porewater will also be investigated.

**Projected Output:**

Collection of data to improve the understanding of the chemical and hydrological processes in the organic cover system will result. The final report will include an evaluation on the effectiveness of the potential benefits of using selected organic materials as cover for partially oxidized tailings and pyrrhotite. The data gathered during this project would provide valuable information for industry and government on closure designs for various sites.

### *PREVENTION AND CONTROL -Waste Rock*

| | |
|---|---|
| **Project 2.31.1c**: | Additional Monitoring of the Composite Cover at Heath Steele |
| Budget: | $ 50,000 |
| Sponsors: | |
| Noranda - BM&S (Heath Steele) | $ 25,000 |
| CANMET | $ 25,000 |
| Manager: | M. Patterson, Heath Steele Mines |
| Contractors: | Noranda Technology Centre/Heath Steele Mines |

**Objective:**

The objective of the project is to continue performance monitoring of the engineered soil cover placed over waste rock pile 7/12 for a period of two years. The performance of the cover will be assessed in reference to pile 18B, which does not have a soil cover.

**Fit with Program:**

Heath Steele, located north of Newcastle, New Brunswick has been the site of acidic drainage research under MEND since 1988. The main project, 2.31.1a, involved the characterization of four existing waste rock piles, and then the design of an engineered soil cover over one of the piles. Construction of the engineered cover was completed in September 1991 (2.31.1b).

The engineered soil cover utilized locally available cover materials, and was designed to reduce oxygen infiltration into the waste pile, and thus limit or prevent the generation of ARD. With a broad set of monitoring instrumentation installed in the pile and cover during construction, the performance of the pile has been continuously monitored.

Of critical importance for evaluating the effectiveness of the engineered soil cover, is the results of water chemistry from seepages emanating from the pile. The unique design of the cover allows a full water balance to be calculated, and this has shown an infiltration rate of about 2% of precipitation. However, the water quality of the effluent has not significantly changed, and this aspect will be further studied by the continued monitoring.

Previous programs have created a database and field test site which offer a unique opportunity to assess the effectiveness of engineered soil covers in reducing the generation of acidic drainage from waste rock piles. The proposed program will continue to monitor the performance of the cover for a further two-year period.

**Projected Output:**
The work will help to assess the effectiveness of engineered soil covers for the reduction of acidic drainage within oxidized, mine waste rock piles. Additionally, the continued monitoring of the water quality emanating from the pile will further define the role that these types of covers could play in mine site reclamation. The data will also be used in a design criteria document that can be used by others for construction purposes.

### *PREVENTION AND CONTROL -Waste Rock*

| | |
|---|---|
| **Project 2.36.3**: | Review of Methods for Characterization of Waste Rock Prior to Underwater Disposal |
| Budget: | $ 30,000 |
| Sponsor: | To be determined |
| Manager: | W. Price, BC MEMPR |
| Contractor: | To be determined |

**Objective:**

The objective of this project is to review the possible means of materials characterization, to evaluate the cost benefit and to recommend a recipe of methods for determining the impact on water quality resulting from the underwater disposal of oxidized waste rock.

**Fit with Program:**

Several methods are available to prevent the generation of acidic drainage from mine wastes. One method that is commonly used to prevent acidification is the placement of acid generating materials underwater. Covering the mine waste with water will minimize the transport of oxygen and therefore limit or even totally prevent acid generation. However, if the waste material has already oxidized, it may contain significant amounts of readily soluble deleterious substances that dissolve into the water cover making underwater disposal less attractive. From the early days of mining, there is a legacy of potentially acid generating waste rock in which significant oxidation has already taken place. For many of these wastes, underwater disposal is an attractive means for arresting the acid generation. However, there is considerable uncertainty about the consequent effect of secondary mineral solubility on water quality.

Previous work to predict the acid rock drainage potential of a particular rock type is based on using fresh materials created by the mining operation. What is envisaged in this project is a review and evaluation of prediction techniques, especially kinetic test procedures, to assess their reliability when applied to oxidized materials and to recommend those with the most promise for determining the potential for predicting the impact if oxidized waste rock is placed underwater. The development of a test protocol with identification of the type of materials tested and the particle size fraction to use, should result.

**Projected Output:**

A review of methods for determining the rate and form of metal release and the resulting total metal loadings is very useful information for those in the mining industry contemplating the placement of oxidized wastes under water. The developed protocol could be tested at a particular site (e.g. Eskay, Heath Steele - Stratmat) where oxidized waste rock will be placed under water.

***PREVENTION AND CONTROL -Waste Rock***

| | |
|---|---|
| **Project 2.37.1**: | Layering Different Types of Waste Rock to Create a Non-acid Generating Composite - Case Studies |
| Budget: | $ 50,000 |
| Sponsor: | To be determined |
| Manager: | W. Price, BC MEMPR |
| Contractor: | Competitive bidding |

**Objective:**

The objective of this project is to complete a case study review on the use of blending as a close-out option for mines that contain both acid generating and non-acid generating waste rock.

**Fit with Program:**

Many British Columbia mines contain both acid generating and non-acid generating waste rock. Where the excess alkalinity is sufficiently large, the two materials can be combined to create a non-acid generating composite. This process requires detailed monitoring, separate materials handling and blending during waste disposal. Typically, blending is achieved by sequential deposition of the different materials in adjacent layers of experimentally defined proportions.

It is expected that there are a number of relevant studies in this area that have been or are being carried out in and outside of Canada. MEND committee members have identified several cases where blending, achieved through adjacent layering, has been used (e.g. Elk, QR Gold, Samatosum, and at coal mines in eastern USA) and others where blending is being considered as a close-out option (e.g. Telkwa). The particulars involved in each of the scenarios would be useful information for operators contemplating a similar disposal technique as part of their waste management philosophy. Recommendations of research needs should also be included in the final report.

This project will complete a review of all scenarios identified in Canada, U.S.A. and other parts of the world (emphasis on North American and Scandinavian countries) where layering has been conducted or was evaluated. Each case would be summarized and specific details would be collected. Some of the more important data to be collected, to name a few, could include: depositional sequence; depth of layers; and prediction methods and success.

**Projected Outputs:**

The type of information collected on all known sites will be a very useful reference document for those in the mining industry contemplating or designing layering as a close-out option, and to regulators evaluating blending proposals.

***PREVENTION AND CONTROL -Waste Rock***

**Project 2.37.2**: Review of Methods for Delaying Onset of Acidic Drainage - Case Studies
Budget: $ 50,000
Sponsor: To be determined
Manager: W. Price, BC MEMPR
Contractor: Competitive bidding

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**Objective:**

The objective of the project is to investigate the use of temporary methods for delaying the onset of acid generation, and to present the findings in a case study format.

**Fit with Program:**

Various methods can be used to prevent sulphitic surfaces or waste rock from producing acidic drainage. These include blending with non-acid generating materials and depositing the waste underwater in tailings impoundments or in flooded underground workings. However, in many cases there is a long delay before the prevention technique can be applied. For example, if the storage site or surface is in a pit or underground mine, disposal and subsequent flooding could not occur until the workings were no longer active. Blending operations may be delayed by a temporary lack of the alkaline rock type and the deposition of low grade ore will be constrained by mineral prices. For all of the above, there may be a need for shorter term, stop gap prevention methods.

It is expected that there are a large number of mines that have been or are planning to use different methods for delaying the onset of acid generation in Canada (Heath Steele, Cinola), Europe and the U.S. The primary goal of the project is to document the practical field experience and provide a critical review of the state-of-the-art for interim techniques that could be used for short term relief prior to permanent prevention.

The materials, methods and reasons for decisions involved in each of the case studies, actual and proposed, would be useful information for operators contemplating a similar disposal technique as part of their waste management philosophy. The report should include a methods manual that evaluates the technical feasibility of each procedure for site specific applications. Recommendations of research needs will also be included in the final report. The intent of the final report is to allow operators to assess these interim options for site specific applicability prior to long term disposal.

**Projected Outputs:**
The type of information collected on all known sites will be a very useful reference document for those in the mining industry contemplating or evaluating methods for delaying the onset of acidic drainage in the short term before permanent disposal measures are taken for close-out.

### *PREVENTION AND CONTROL -Waste Rock*

**Project 2.37.3**: Characterization of Test Materials from Samatosum Column Study
Budget: $ 35,000
Sponsor: To be determined
Manager: W. Price, BC MEMPR
Contractor: To be determined

**Objective:**
The general objective of this project is to gain a better understanding of the relative effectiveness of the acid consuming layers in preventing and controlling oxidation and hence acid generation in waste rock, both under controlled and field conditions.

**Fit with Program:**
The waste dump design at Samatosum was for alternating layers of acid consuming rock types and potentially acid generating (PAG) waste rock. This has had the effect of encapsulating PAG material in an envelope of acid consuming material. A laboratory simulation (column leach test program) of the proposed waste dump geometry was initiated in February 1989 to test the validity of the waste dump design hypothesis, and on the basis of its early results the proposed layering procedure was used by the mine.

The laboratory study consisted of six columns containing various proportions of the acid consuming dolomitic mafic pyroclastic (MAF), and mixed PAG rock types. Both the field and laboratory results, after 260 weeks, indicate that the layering technique has been effective in controlling acid generation from the PAG blend material and that the layered waste rock are not expected to turn acid at any time.

The combination of extensive field monitoring of the actual dumps and the five years of column leachate monitoring provide a rare opportunity to compare laboratory simulations with the resulting performance of layering as a means of ARD prevention. A comprehensive analysis of the residual materials in the columns will be completed and the results linked with the field program.

**Projected Outputs:**
A comprehensive analysis of the materials from the columns will help determine whether the initial conclusions, based on limited leachate analyses, were accurate. Monitoring data on such items as the reactivity and weatherability of sulphide and carbonate minerals, the effect of layering on acid production and mechanisms of acid production in well buffered samples will be included in the final report. This would give industry and government a better perspective of blending as an option for the control of acid generating waste.

*TREATMENT*

**Project 3.41.2:** Metal and Sulphide Surface Biomineralization
Budget: $20,000
Sponsor:
Environment Canada ............................................. $20,000
Manager: Bill Blakeman
Contractor: Waste Water Technology Centre - "New Ideas" Proposal

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**Objectives:**

To develop a biomineralization process to biologically immobilize leachable and soluble metals in acid-generating waste rock and tailings.

**Fit With Program:**

Tests on the use of a biological system for the detoxification of cyanide waters from heap leaching have shown that soluble metal levels and sulphate oxidation rates were lowered. These observations led the proponent to propose that metal biomineralization could be used as an in-situ treatment option for acid-generating waste sites.

Such a system may have economic use in certain situations such as temporary prevention of acid generation in a waste rock pile, while the rock is being stored awaiting final disposal into a mined-out open pit.

The tests will use native microorganisms from the Mine Doyon and Island Copper mines. Column tests will follow flask tests, which will then be followed by humidity cell and column tests.

This project was submitted to the New Ideas Task Force, who in turn passed it on to the Treatment committee who recommended that the project be approved for funding.

**Projected Outputs:**

If successful, the results of the laboratory tests will be used to design field tests and to conduct a preliminary economic feasibility study.

## *TREATMENT*

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|---|---|
| **Project: 3.42.2** | Lime Sludge Stabilization, Disposal and Use |
| Budget: | $105,000 |
| Sponsors: | To be determined |
| Manager: | To be determined |
| Contractor: | Competitive bidding |

**Objectives:**
To evaluate and document methodology for the long term stabilization, disposal and potential beneficial use of lime treatment sludge.

**Fit With Program:**
Lime treatment will be the principal method for treating acidic water for the foreseeable future, and this activity represents a large proportion of the liability of acid generating mine wastes. Although lime treatment technology is well developed, a good understanding of the best methods for sludge stabilization and disposal under a wide range of conditions is not well developed.

The principal concerns about the treatment sludge are the volume occupied by the sludge and the chemical stability of the sludge, particularly with respect to heavy metals that have been coprecipitated with gypsum, and aluminum and iron hydroxides.

This project will summarize methods for minimizing sludge volume, and engineering disposal methods for preventing the mobilization of heavy metals in the long term (100's of years).

Although the project will focus on gathering information on and analyzing available practices, some laboratory investigations are likely required for this work.

The use of lime treatment sludge has been suggested as a material to create low permeability for either oxygen or water. A MEND associate project in New Brunswick on the use of lime sludge as a component in the capping of a rock pile will provide important information for this work. Other use possibilities will be investigated, including the experience at other mine sites in sludge use.

**Projected Outputs:**
This project will complete the Treatment component of the MEND program, and will form an important part of the "MEND Manual" to be completed by 1998. With the documentation produced from this project, operators and designers of lime treatment plants will more precisely be able to plan for long term treatment strategies, where other AMD treatment options are unavailable or uneconomic.

*MONITORING*

**Project 4.5.4**: Environmental Monitoring Handbook for Acid Mine Drainage
Budget: $80,000
Sponsors: ......................................................................................
CANMET ........................................................... $40,000
Ontario ..................................................... $40,000
Manager: To Be Determined
Contractor: To Be Determined

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**Objectives:**

The objectives of the proposed project are to provide, in a concise format, a working program with explanations of the advantages and limitations of particular monitoring approaches. This will include: a description of the principles, concepts and limitations in developing monitoring programs; a description of acid mine drainage (AMD) and acid rock drainage (ARD) processes, including the mine site components involved; specific AMD and ARD sources, pathways and receptors; a description of the various sampling techniques and parameters used in monitoring AMD and ARD sources; pathways and receptors for contaminant impact. This includes the methodology, equipment, quality assurance/quality control considerations; the advantages and limitations of techniques and parameters; and guidance on the statistical treatment of data collected and data management.

**Fit With Program:**

A draft Acid Rock Drainage Technical Guide was produced in 1989 by the B.C. AMD Task Force. Since that time the B.C. AMD Task Force and MEND monitoring subcommittees have sponsored various literature reviews and monitoring projects to address deficiencies of the guides' monitoring chapter. Projects aimed at simplifying the sampling of tailings and waste rock and the monitoring of mine wastes producing acid using remote sensing and geophysical techniques have been completed. The proposed project will use the B.C. guide as a template to prepare an updated monitoring manual for waste rock and mine tailings. The manual will also address the application of geophysical techniques to monitoring mine tailings and waste rock. The guide will offer a practical guide containing proven technology to guide mining personnel, consultants, and government agencies to make informed decisions on the information gathering process as it relates to the mining industry.

**Projected Outputs:**

## *MONITORING*

A concise manual to assist industry and government agencies across Canada to achieve consistency in implementing monitoring programs, developing comparative data bases, and to assist in the use of appropriate scientific techniques.

*MONITORING*

**Project 4.6.5a**: Demonstration of a Field Method to Determine the Oxygen Flux Across the Surface of Tailings

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| Budget: | $11,100 |
| Sponsor: | |
| INCO | $11,100 |
| Manager: | R. Stuparyk, INCO |
| Contractor: | University of Waterloo |

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**Objective:**

The primary objective is to demonstrate the utility of a new oxygen flux measurement technique to determine the rate of oxygen uptake across the surface of mine tailings. The results will be compared to more conventional test methods currently employed.

**Fit With Program:**

Sulphide oxidation within tailings impoundments is ultimately controlled by the supply of oxygen, whether it is catalyzed by bacteria or not. Thus, the flux of oxygen through the surface of the tailings is an immediate, although indirect measure of the overall sulphide oxidation rate. The amount of oxygen used in the oxidation reactions will enable calculation of the contamination release directly. Previous studies have determined the oxygen flux by measuring the oxygen gradient in the upper portion of the tailings or through chemical analyses of the pore oxidation products. A new method has been devised at the University of Waterloo that measures the oxygen uptake by the tailings and hence, indirectly measures the oxygen flux in a rapid, facile and economical way.

This method can be useful in a number of scenarios. An immediate use is the evaluation of oxidation rates in existing tailings impoundments and compare these values to those determined by other methods. Also, the effectiveness of tailings covers strategies can be measured quickly and economically.

The method requires validation by field trials as proposed by this work.

**Projected Outputs:**

This project will provide the verification of a new, easy-to-use technique that could be used to determine the oxidation rate of mine tailings. This technique has broad application in that data can be acquired and used for predictive modelling. The efficiency of various cover scenarios could be determined accurately, rapidly and economically to assist with close-out scenarios for mine operators.

*MONITORING*

**Project 4.6.5b**: Demonstration of a Field Method to Determine the Oxygen Flux Across the Surface of Waste Rock
Budget: $15,000
Sponsor: ..................................................................................
INCO ........................................................... $15,000
Manager: R. Stuparyk, INCO
Contractor: University of Waterloo

**Objective:**

The primary objective of this work is to extend the evaluation of a new oxygen flux measurement method from tailings to waste rock.

**Fit With Program:**

The development of useful predictive techniques for masses of acid generating waste rock depends on a thorough understanding of the basic principles involved. Sulphide oxidation in waste rock piles is controlled by a number of factors including the supply of oxygen. Thus, by determining the uptake of oxygen by representative samples from a waste rock pile, one can determine the approximate potential for the waste rock to produce acid.

In Canada, the primary concern about sulphide-containing waste rock deposits is that of water quality, principally resulting from the contamination of surface infiltration.

**Projected Outputs:**

This project will provide verification of a new easy-to-use technique for measuring oxidation rate in waste rock.

*TECHNOLOGY TRANSFER*

**Project 5.1.2**: Workshops
Budget: $30,000
Sponsors: ........................................................................................
New Ideas Fund Contributors .................................... $30,000
Manager: MEND Secretariat
Contractor: Ken Wheeland

**Objectives:**

To present workshops on completed topics of the MEND program across Canada.

**Rationale and Fit With Program:**

During 1994, and early in 1995 workshops were presented to technical audiences across Canada. These workshops were well received and both the contractors who were representing their work and the participants found the workshops useful. Also useful feed feedback was received that helped to focus future and final work in the MEND program.

The following topics are proposed for the various locations:

| Topic | Possible Presenter(s) | Possible Location, Date |
|---|---|---|
| Dry Cover Design | Noranda/U. of Sask | Saskatoon,late 1995 |
| Coal- Acid Mine Drainage | Various | Cape Breton, June 1995 |
| Chemical Treatment | SENES | Sudbury, Sept. 1995 |
| In-pit Disposal | SENES | Sudbury, Sept. 1995<br>Also Fredericton (?) |
| In-pit Disposal, Minewall | SENES, Morwijk | Vancouver, Oct. 1995 |
| Chemical Modelling | Various | Montreal, Nov. 1995 |
| Alternate Dry Covers | Lakefield, Roche, École Polytechnique | Val d'Or, Oct. 1995 |
| Underwater disposal | Rescan, UBC | Winnipeg, Sept. 1995 |
| Long Term Monitoring | Various | Early 1996 |

*TECHNOLOGY TRANSFER*

| | | |
|---|---|---|
| Water Covers | Noranda, CANMET, Golder | Montreal, August 1995 |

Workshops to date have been free, but a nominal charge to cover local expenses will be applied. Attendees will receive a copy of relevant reports and workshops results.

**Project 5.6.3**: Fourth International Conference on the Abatement of Acid Rock Drainage

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| Budget: | $80,000 |
| Sponsors: | To be determined |
| Managers: | Mike Filion, Teck<br>George Poling, UBC<br>MEND Secretariat |

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**Objective:**

MEND will sponsor, and host the Fourth International Conference on Abatement of Acid Rock Drainage in Vancouver in June 1997.

**Fit With Program:**

The Fourth International Conference on the Abatement of Acid Rock Drainage coincides with the last year of the MEND program. Over the past few years, MEND and other research initiatives around the world have focussed on the prediction, prevention and control, and long term management of acid generating tailings, waste rock and mine walls. These initiatives have sponsored the development of new technology that is being put in place under a wide variety of conditions.

An "ad hoc" committee has been formed and a professional conference organizer has been engaged to handle logistics and local organization.

The theme of this conference will be **"Application of Technology"**, and the actual conference will be preceded by two days of workshops and short courses, which MEND technical committees will be taking the lead in preparing.

The first notice of this conference is being sent out in early April; special emphasis is being made to attract visitors from outside Canada.

### *TECHNOLOGY TRANSFER*

Total conference budget is estimated to be $400,000, of which $80,000 is estimated to be needed in contributions from many donors including MEND.

*TECHNOLOGY TRANSFER*

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|---|---|
| **Project 5.7.2:** | CD ROM Publication |
| Budget: | $80,000 |
| Sponsors: | To be determined |
| Manager: | MEND Secretariat |
| Contractor: | Competitive bidding |

**Objectives:**

To assemble a library of MEND documentation on a single searchable compact disc.

**Rationale and Fit With Program:**

The increasing mountain of information generated by MEND and others on the subject of acidic drainage is truly overwhelming. One very efficient way to have all of the MEND information in one location **and** accessible is to have all of the MEND reports on a single "CD ROM" disc.

A CD ROM disc with search software attached allows anyone with a CD drive attached to a computer to search any subject or topic, and to produce relevant "hard" paper copies if desired.

Unfortunately a large proportion of MEND reports completed to date are in a variety of formats and computer codes, and in many cases a computer disc of the report does not exist. Also, most recent reports have multi-colour illustrations.

The $80,000 cost is an estimate to scan all past MEND reports and to prepare the compact disc encyclopedia. The work would start in 1995 and will be complete in 1997. This disc will be offered for sale at nominal cost. By having the disc available, a user could get a copy of over 100 MEND reports for less than the cost currently of one MEND report.

The Technology Transfer Committee will monitor carefully the CD ROM technology development over the next two years, to ensure that the technology selected will not be obsolete in the near future.

## PREDICTION/PRÉVISION

1.11.1 Critical Literature review of Acid Drainage from Waste Rock. April 1991. $25

1.14.2a Diversitémicrobiologique dans la production de drainage minier acide à la halde sud de la Mine Doyon, March 1994. $30

1.14.2b Development of a Modified MPN Procedure to Enumerate Iron Oxidizing Bacteria, March 1994. $20

1.14.2c Heat Transfer During Acid Mine Drainage Production in a Waste Rock Dump, La Mine Doyon (Québec), March 1994. $25

1.14.2d Monitoring of Acid Mine Drainage: Chemical Data from La Mine Doyon-South Waste Rock Dump, March 1994. $25

1.14.2e Water Budget for the Waste Rock Dump at "La Mine Doyon" Québec, March 1994. $30

1.14.2f Mineralogical Transformations Associated with AMD Production in a Waste Rock Dump - La Mine Doyon-South Waste Rock Dump. March 1994. $20

1.14.2g Monitoring and Modelling of Acid mine Drainage from Waste Rocks Dumps - La Mine Doyon, September 1994. $35

1.16.1a Investigation of Prediction Techniques for Acid Mine Drainage, November 1989. $25

1.16.1b Acid Rock Drainage Prediction Manual, March 1991. $40

1.16.1c New Methods for Determination of Key Mineral Species in Acid Generation Prediction by Acid-Base Accounting. April 1991. $25

1.17.1a Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec - 1985 Program, July 1986. $25

1.17.1b Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 2 - 1986 Program, July 1987. $25

1.17.1c Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Volume I Report, May 1988. $25

Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Volume II - Appendices, March 1988. $25

Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Supplementary Report, March 1989, $25

1.17.1d Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Quebec, "Generation and Evolution of Acidic Pore Waters at the Waite Amulet Tailings - Final Report", April 1990. $60

1.19.1 Long Term Acid Generation Studies: Cinola Project British Columbia (includes diskette), March 1994. $35

1.21.1a Critical Review of the Reactive Acid Tailings Assessment Program (RATAP.BMT2), April 1990. $30

1.21.1b Workshop on Modelling of Reactive Tailings Sponsored by the MEND Prediction Committee, Final Report, August 1990. $40

1.22.1a Field Procedures Manual: Gas Transfer Measurements Waste Rock Piles Heath Steele Mines New Brunswick, March 1994. $30

1.25.1 Soilcover Users Manual Version 1.0 (includes diskettes), March 1994. $40

1.32.1 Prediction and Prevention of Acid Rock Drainage from a Geological and Mineralogical Perspective, October 1993. $35

1.51.1 Quantitative Analysis of Chemical and Biological Kinetics for the Acid Mine Drainage Problem, June 1994. $30

1.51.2 Nonlinear Modelling of Chemical Kinetics for the Acid Mine Drainage Problem and Related Physical Topics, October 1993. $25

## PREVENTION AND CONTROL/PRÉVENTION ET CONTRÔLE

2.11.1a Subaqueous Disposal of Reactive Mine Wastes: An Overview, June 1989. $25

A Preliminary Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1990. $25

A Preliminary Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba, March 1990. $25

A Preliminary Assessment of Subaqueous Tailings Disposal in Mandy Lake, Manitoba, March 1990. $25

Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia, March 1990. $25

2.11.1b Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Snow Lake Area, Manitoba, September 1990. $25

Geochemical Assessment of Subaqueous Tailings Disposal in Mandy Lake, Flin Flon Area, Manitoba. September 1990. $25

2.11.1c A Preliminary Biological and Geological Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1991. $25

Chemical Diagenesis of Submerged Mine Tailings in Benson Lake and Natural Sediments in Keogh Lake, Vancouver Island, British Columbia, June 1992. $25

2.11.1d A Critical Review of MEND Studies Conducted to 1991 on Subaqueous Disposal of Tailings, July 1992. $25

2.11.2a Literature Review Report: Possible Means of Evaluating the Biological Effects of Sub-Aqueous Disposal of Mine Tailings, March 1993. $25

2.13.2a Expérimentation de l'inondation du parc à résidus miniers - Solbec Cupra (Phase IV). Rapport Sommaire, Décembre 1993. $35

2.13.2b Flooding of a Mine Tailings Site - Solbec Cupra. Suspension of Solids: Impact and Prevention, March 1994. $25

2.13.2c Inondation artificielle du parc à résidus miniers Solbec Cupra: Études microbiologique et chimique - Rapport final, Mars 1994. $35

2.20.1 Evaluation of Alternate Dry Covers for the Inhibition of Acid Mine Drainage from Tailings, March 1994. $30

2.21.1 Development of Laboratory Methodologies for Evaluating the Effectiveness of Reactive Tailings Covers (includes diskette), March 1992. $40

2.23.2ab Hydrologic and Hydrogeologic Evaluation of the Thickened Tailings Disposal System at Kidd Creek Division, Falconbridge Limited, October 1993. $35

2.24.1 Manual of Methods Used in the Revegetation of Reactive Sulphide Tailings Basins, November 1989. $20

2.25.1a Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost: Literature Review and Recommendations, July 1992. $25

2.31.1a Heath Steele Waste Rock Study, Phases 1 to 3, March 1992. $40

2.31.1b Engineering Design and Construction Phase IV - Composite Soil Cover Acid Waste Rock Study Heath Steele Mines, November 1994. $30

2.32.3a Injection de résidus miniers dans des stériles miniers comme moyen de réduction des effluents acides, janvier 1994. $20

2.35.2a Evaluation of Techniques for Preventing Acidic Rock Drainage: First Milestone Research Report, October 1993. $35

2.44.1 Microbial Plugging of Uranium Mine Tailings to Prevent Acid Mine Drainage - Final Report, December 1992. $25

*MEND Reports Available Continued...*
*Rapports Disponibles sur NEDEM la suite...*

2.45.1a Separation of Sulphides from Mill Tailings - Phase I, June 1994. $30

## TREATMENT/TRAITEMENT

3.11.1 Treatment of Acidic Seepages Using Wetland Ecology and Microbiology: Overall Program Assessment, July 1993. $35

3.12.1a Assessment of Existing Natural Wetlands Affected by low pH, Metal Contaminated Seepages (Acid Mine Drainage), May 1990. $25

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